NASA CR-165,818

NASA CONTRACTOR REPORT
FINAL REPORT 165816

LAMINAR FLOW CONTROL SPF/DB FEASIBILITY DEMONSTRATION

R. C. ECKLUND
N. R. WILLIAMS

Douglas Aircraft Company
Long Beach, California 90846

Contract NAS1-16425
October 1981

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Langley Research Center
Hampton Virginia 23665

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N82-21532 #

PREFACE

This document is the final report covering the Engineering development and demonstration of the feasibility of the use of SPF/DB titanium for laminar flow control system concepts. This effort is titled "LAMINAR FLOW CONTROL SPF/DB FEASIBILITY DEMONSTRATION".

Work was conducted in two major tasks:

(1) Control of surface condition to achieve required smoothness and (2) fabrication of two demonstration panels, one smooth and one LFC treated. The report covers the work conducted from September 26, 1980 to October 1981. The NASA technical monitors were Mr. Daniel B. Snow of the Aeronautical Systems Division, and Mr. J. W. Cheely of the Laminar Flow Control Project Office, both at Langley Research Center.

The studies and demonstration panels were accomplished within the Design Engineering Department of Douglas Aircraft Company. Engineering team members assigned to this contract are listed below, along with primary areas of contribution:

M. Klotzsche	Program Manager - ACEE
W. E. Pearce	Project Manager - LFC
N. R. Williams	Principal Investigator
R. C. Ecklund	Task Leader - M&PE
E. B. Herley	Resource and Schedule Control

CONTENTS

1.0 SUMMARY

This report describes development of procedures for the fabrication of two superplastic formed, diffusion bonded (SPF/DB) titanium panels for demonstration of a laminar flow control (LFC) porous panel concept.

Procedures were developed to produce panels, using thin (0.016 inch) core and face sheets, having smooth, defect free surfaces suitable for LFC applications.

The first panel was flat on both sides to demonstrate the capability of producing smooth, defect free panel surfaces. The second panel was flat on the bottom side and formed on the top side for LFC treatment. Holes were machined into the top side, and a perforated titanium sheet was adhesively bonded to land areas formed adjacent to the holes. Tnis panel demonstrated that SPF/DB titanium is a process adaptable to LFC applications.

2.0

INTRODUCTION

A process has been developed at the Douglas Aircraft Company combining welding and superplastic forming diffusion bonding (SPF/DB) of titanium to fabricate expanded core sandwich panels. The process is illustrated in Figure 2.1. The top illustration shows the core envelope, which is comprised of two sheets, resistance roll spot welded in a rectangular pattern and seam welded around the edge for sealing. The second illustration shows the core envelope in the process of forming. The forming is accomplished by argon gas pressure during the period of temperature rise from 1500°F to 1700°F. For clarity, the face sheets are not shown in these illustrations. The bottom illustration shows the core envelope formed against the face sheets. Two gas ports are required; one to form the face sheet envelope and one to form the core envelope. Face sheet pressure forms the face sheets against the limiting fixtures. This pressure is maintained throughout the core forming cycle to hold the face sheets in place and restrain material gathering (eyebrowing) as the core cells form against the face sheets. Since the process involves forming of the core envelope within the face sheet envelope, face sheet gas must be vented through the gas supply tube during core forming. After core forming, the face sheet pressure is reduced and the core envelope is held under pressure at 1700°F for diffusion bonding of the cell walls to their neighbors and to the face sheets.

Using the process, panels with a variety of core configurations have been fabricated.

The purpose of this program was to demonstrate the feasibility of utilizing the SPF/DB process to fabricate lightweight titanium substructure for LFC applications. Advantages inherent in SPF/DB substructure over nonmetallics are cost savings, potential weight savings due to increased strength, improved endurance under extreme environmental conditions and improved maintainability.

Use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

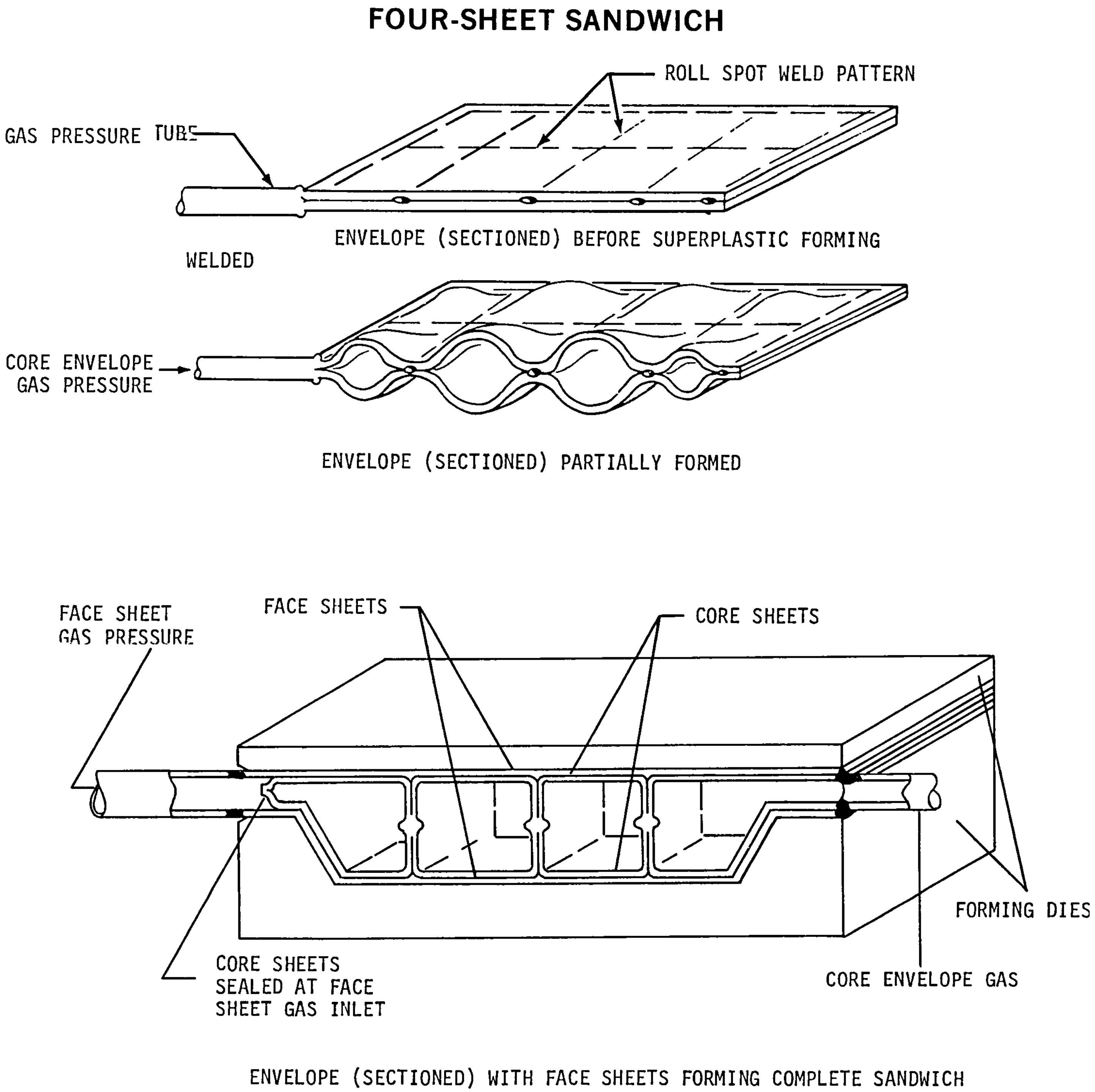


FIGURE 2.1 **SPF/DB PHASES OF FABRICATION**

3.0 PROCESS DEVELOPMENT

3.1 SURFACE CONDITION

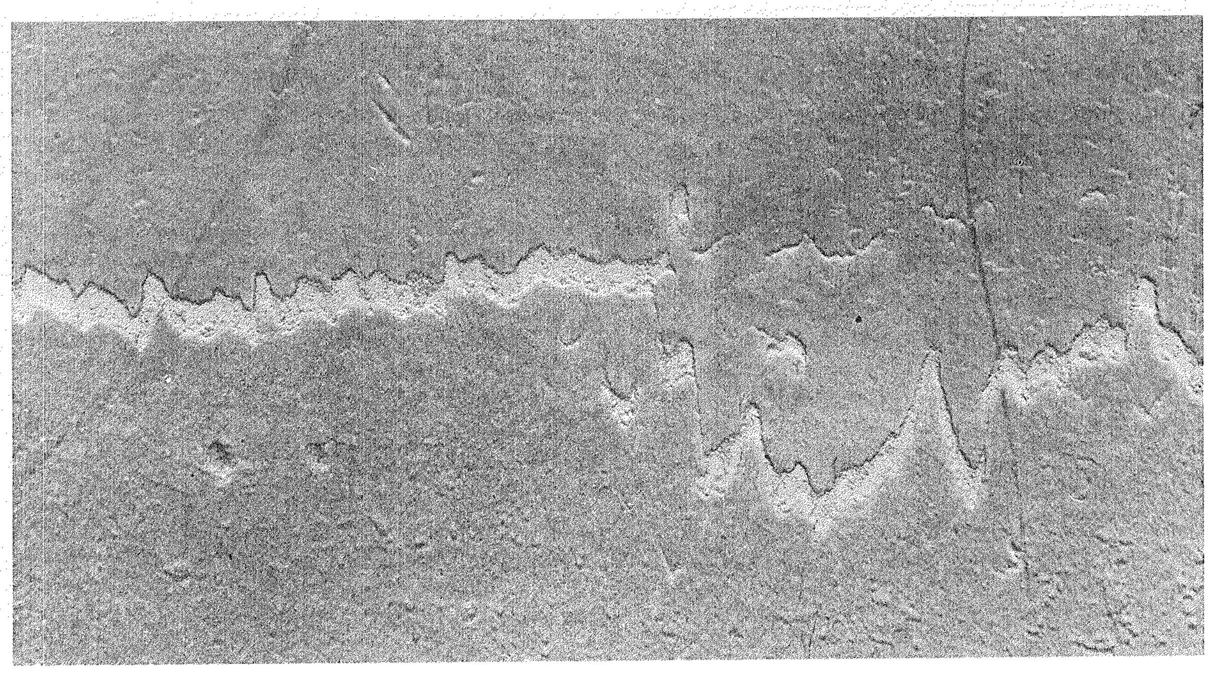
A problem which occurs in varying degrees in superplastic forming/diffusion bonding of titanium is reaction of the titanium with the tooling material. Figure 3.1-1 shows a sample of surface reaction, commonly called tooling pick-up, as it appears on the surface of a formed panel face sheet. Figure 3.1-2 shows a section through an area of reaction photographed at low magnification to illustrate the characteristics of the surface embrittled layer (white layer) as it is influenced by tooling pick-up. It can be seen that the white layer is a normal depth of approximately 0.003 inch in the area of no tooling pick-up. The white layer beneath the tooling pick-up, however, has a depth of approximately 0.009 inch. Figure 3.1-3 shows the microstructure of the surface reaction and the surrounding affected material. The constituents of the surface reaction layer have been analysed by X-ray Energy Spectrometry (XEM). Figure 3.1-4 shows a scan taken from a titanium surface containing no tooling pick-up. Figure 3.1-5 shows a scan taken from an area of tooling pickup. This scan reveals an intermetallic layer of titanium, iron, chromium, and nickel. The intermetallic is not removable by chemical milling which necessitates removal by power sanding. Complete removal of the white layer requires chemical milling after sanding to the depth of the layer in the area of tooling pick-up. Surface removal to this depth is acceptable, provided the final thickness after chemical milling meets the design requirements. In this program, forming of the face sheets and core into 0.240 inch diameter holes was required for the final LFC demonstration panel. It was determined by calculation that a face sheet thickness no greater than 0.016 inch was required to provide tight forming into the tooling holes. Tooling pick-up, as described, would be unacceptable in this design since the depth of the affected material is approximately one-half of the starting face sheet thickness.

Initial work in this program was directed towards development of procedures to produce smooth, defect free face sheet surfaces.

Standard practice prior to this program has been to form the face sheets against type 321 CRES slip sheets. Both the slip sheets and the panel face sheets are sprayed with a 1 to 1 mixture of boron nitride powder and binder (Wall Colmonoy Nicro braze cement, viscosity 600).

The face sheet forming pressure commonly is held at 10 psi until the part temperature indicates 1300°F, at which time the face sheet pressure is increased to 50 psi. Subsequent to this change in face sheet pressure, at an indicated panel temperature of 1550°F, the core forming cycle is initiated.

Figure 3.1-6 shows the bottom side of Panel No. 1 formed using the practices described. Tooling pick-up on this panel is peripheral and random. Figure 3.1-7 shows the top face sheet of this panel where forming is less severe than bottom sheet forming. This side shows peripheral irregularities of less severity than those on the bottom side. The core did not fully form in this panel due to blockage of the core gas tube during the run. Figures 3.1-8 and 3.1-9 show the bottom and top face sheets, respectively, of Panel No. 2 which was formed using the same practices as described, except that the binder in this case was thinned with acetone in a 1 binder, 3 acetone mixture. This panel core was fully formed. The bottom face sheet has severe peripheral tool pick-up. The top face sheet has surface irregularities in a pheripheral and random pattern. Tool pick-up is not always obvious by appearance alone. Figure 3.1-10 shows the bottom surface of this panel after power sanding of



Neg. LV-1058 MAG. 4X

FIGURE 3.1-1 TOOLING PICK-UP ON TITANIUM SURFACE

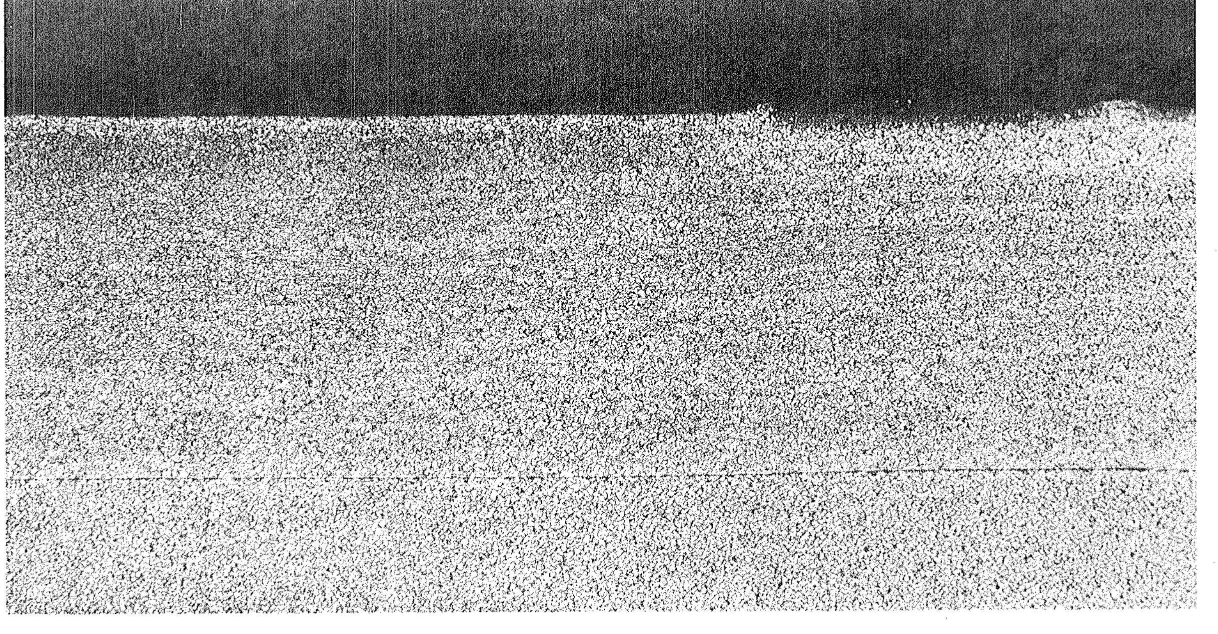


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FIGURE 3.1-2 CROSS SECTION THROUGH TOOLING PICK-UP AND ADJACENT AREA

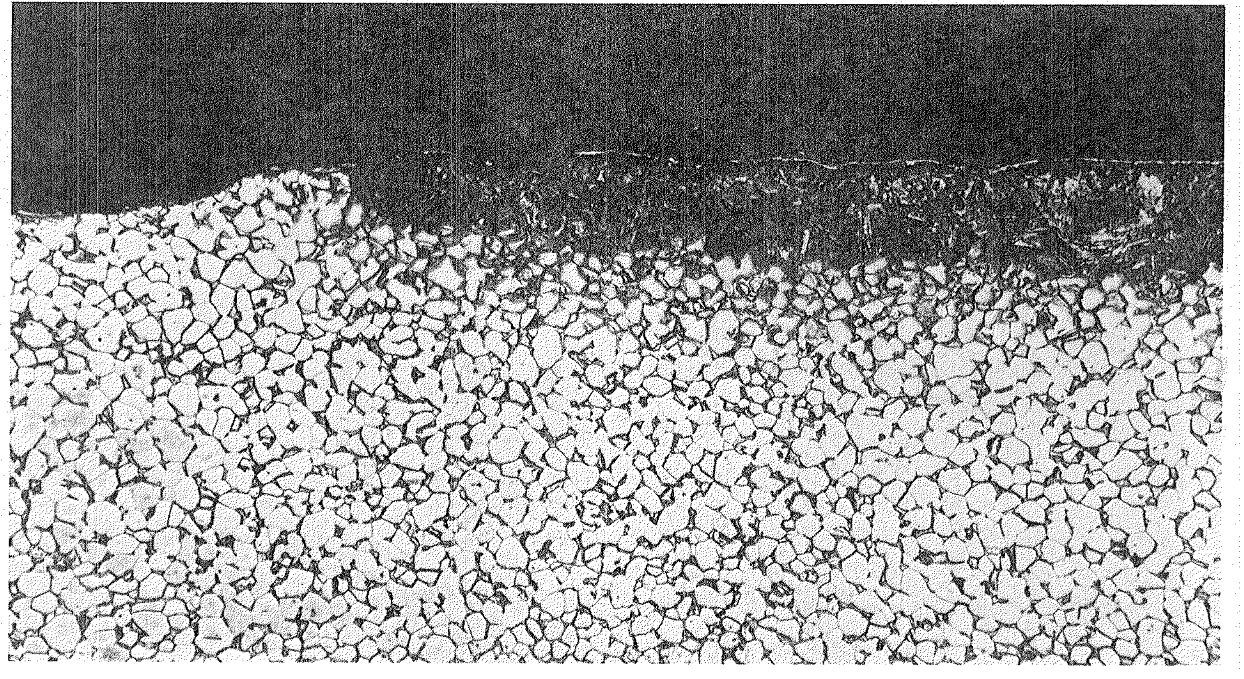

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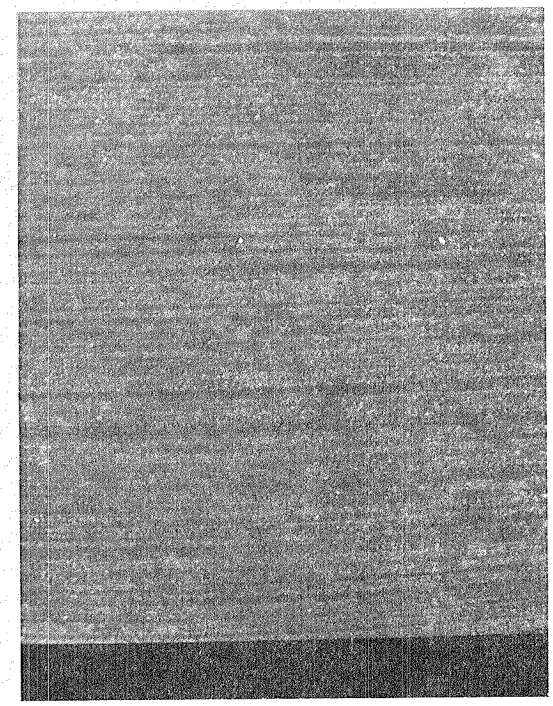
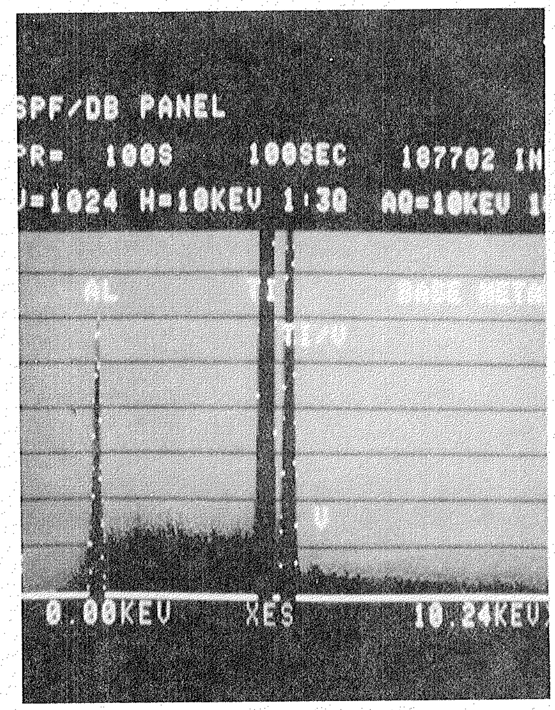
FIGURE 3.1-3 MICROSTRUCTURE AT TOOLING PICK-UP SHOWING INTERMETALLIC LAYER

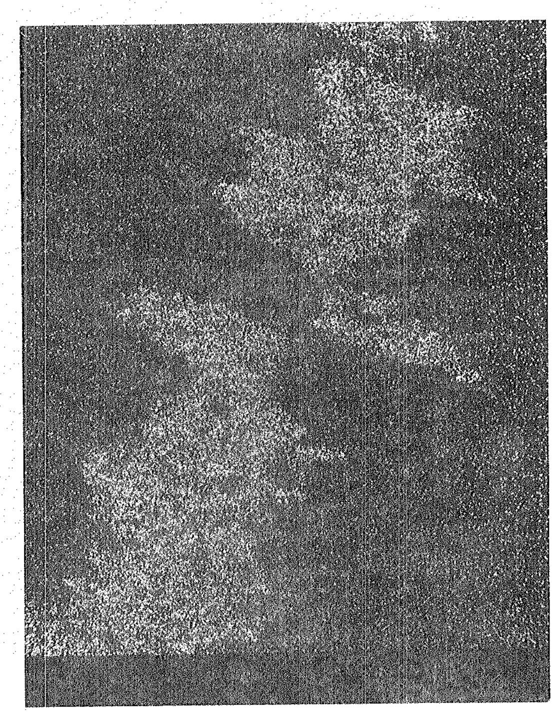


SV-1632 BASE MATERIAL MAG. 20X

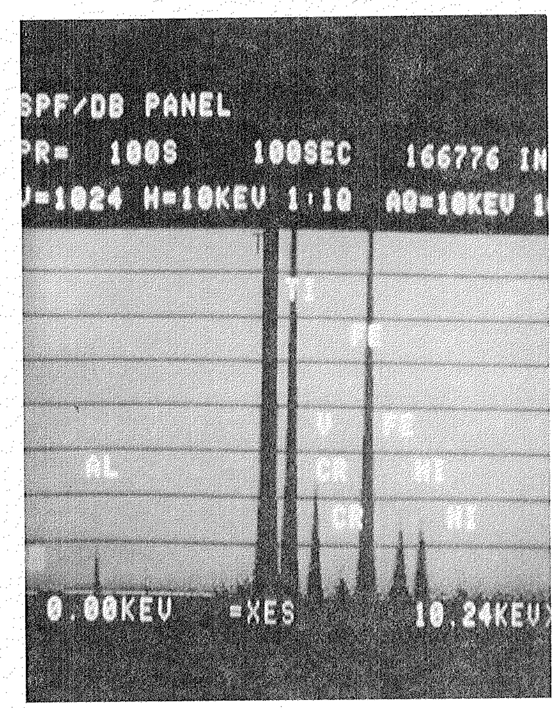


SV-1633 XEM SCAN MAG. 20X

FIGURE 3.1-4 XEM SCAN OF Ti-6Al-4V BASE MATERIAL



SV-1630 TOOLING PICK-UP MAG. 20X



SV-1631 XEM SCAN MAG. 20X

FIGURE 3.1-5 XEM SCAN OF TOOLING PICK-UP

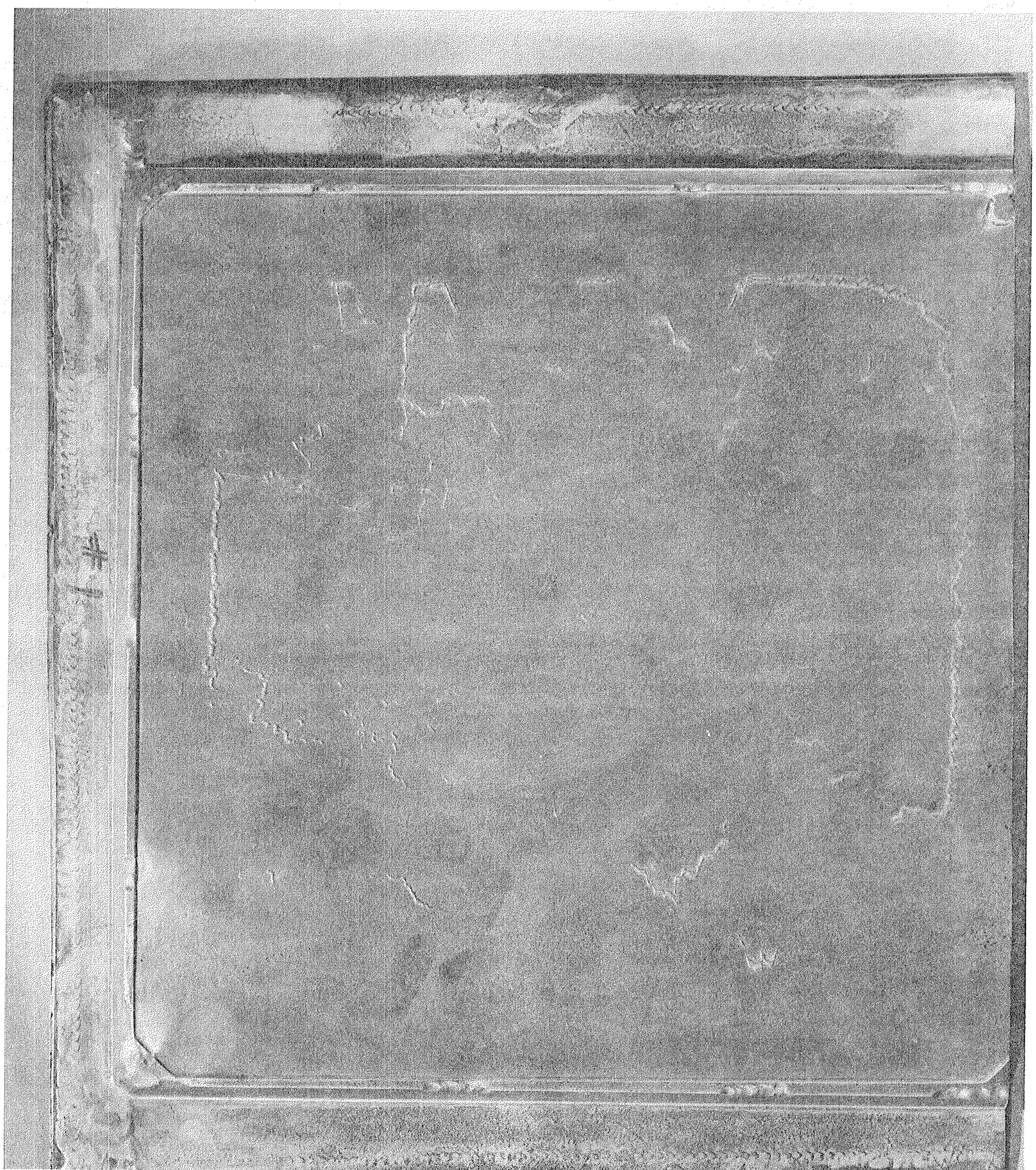


FIGURE 3.1-6 PANEL NO. 1 BOTTOM FACE SHEET

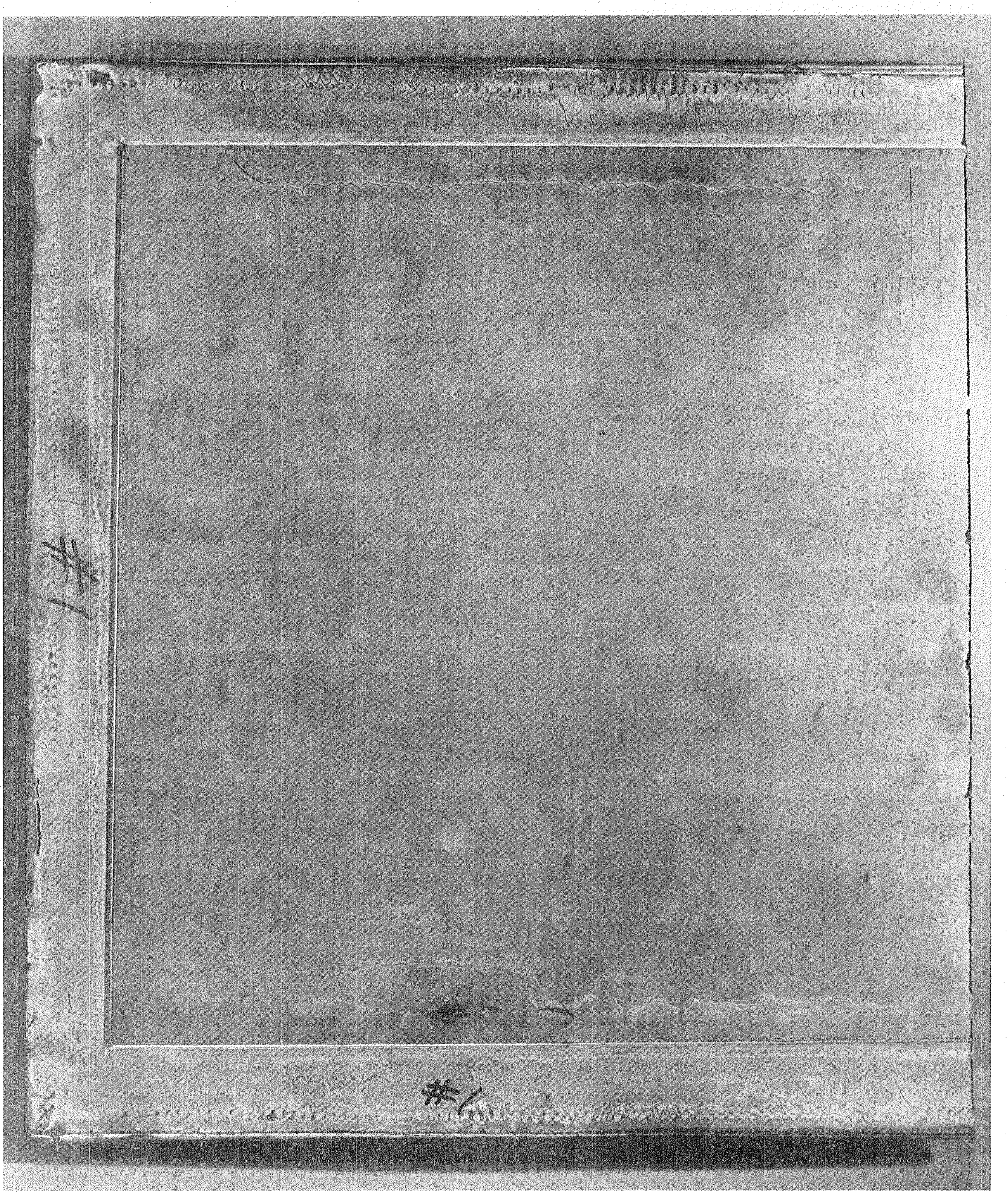


FIGURE 3.1-7 PANEL NO. 1 TOP FACE SHEET

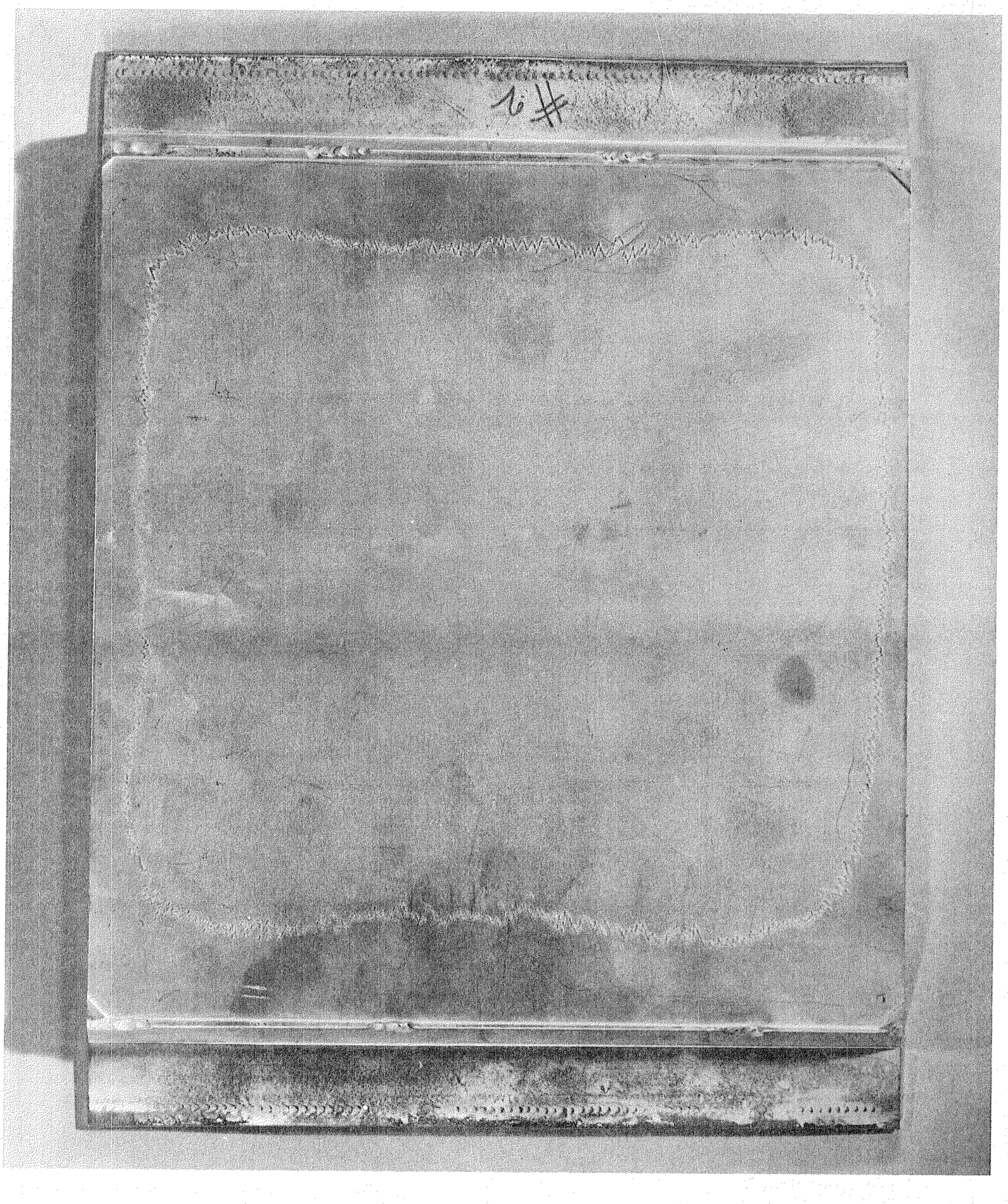


FIGURE 3.1-8 PANEL NO. 2 BOTTOM FACE SHEET

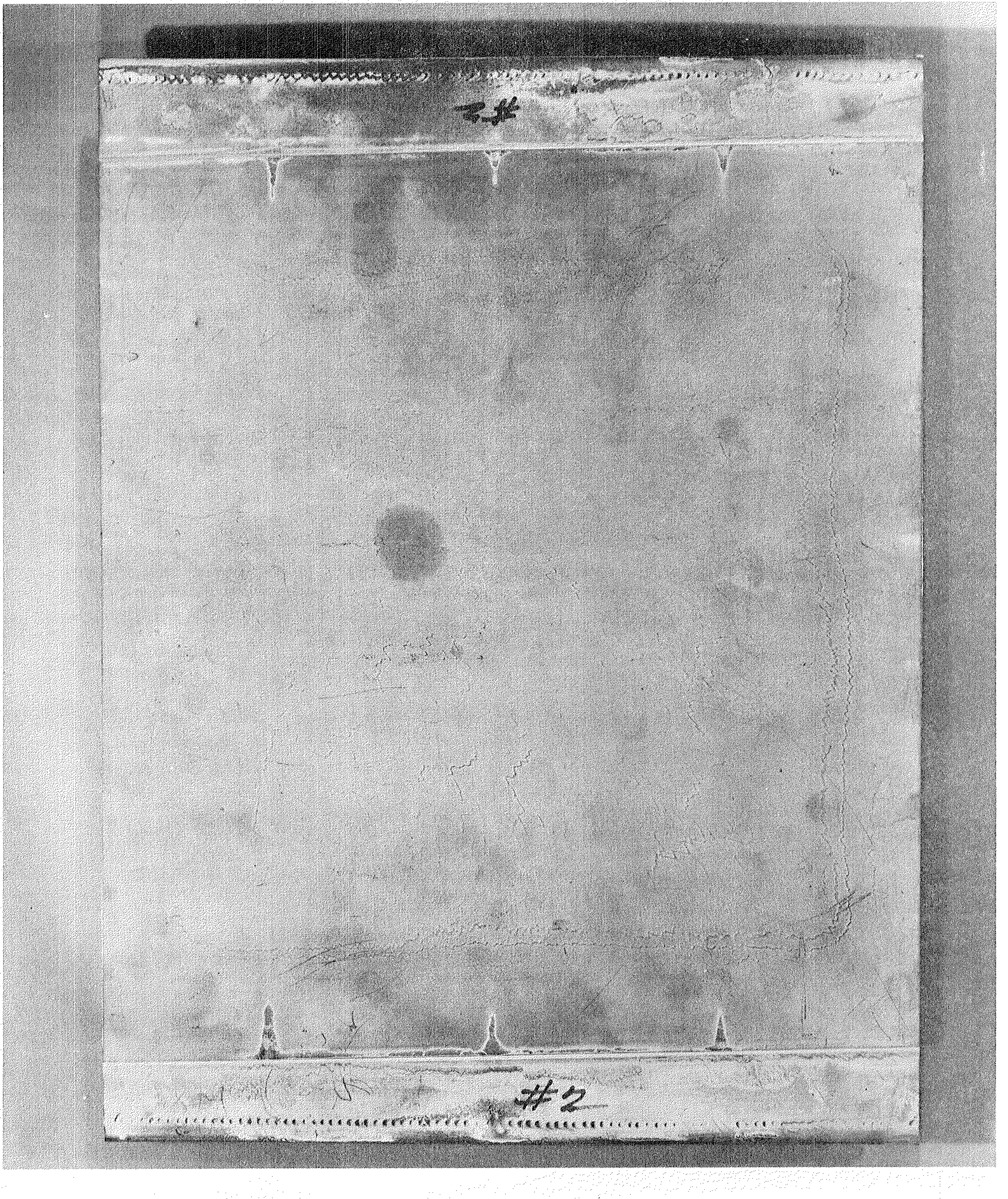


FIGURE 3.1-9 PANEL NO. 2 TOP FACE SHEET

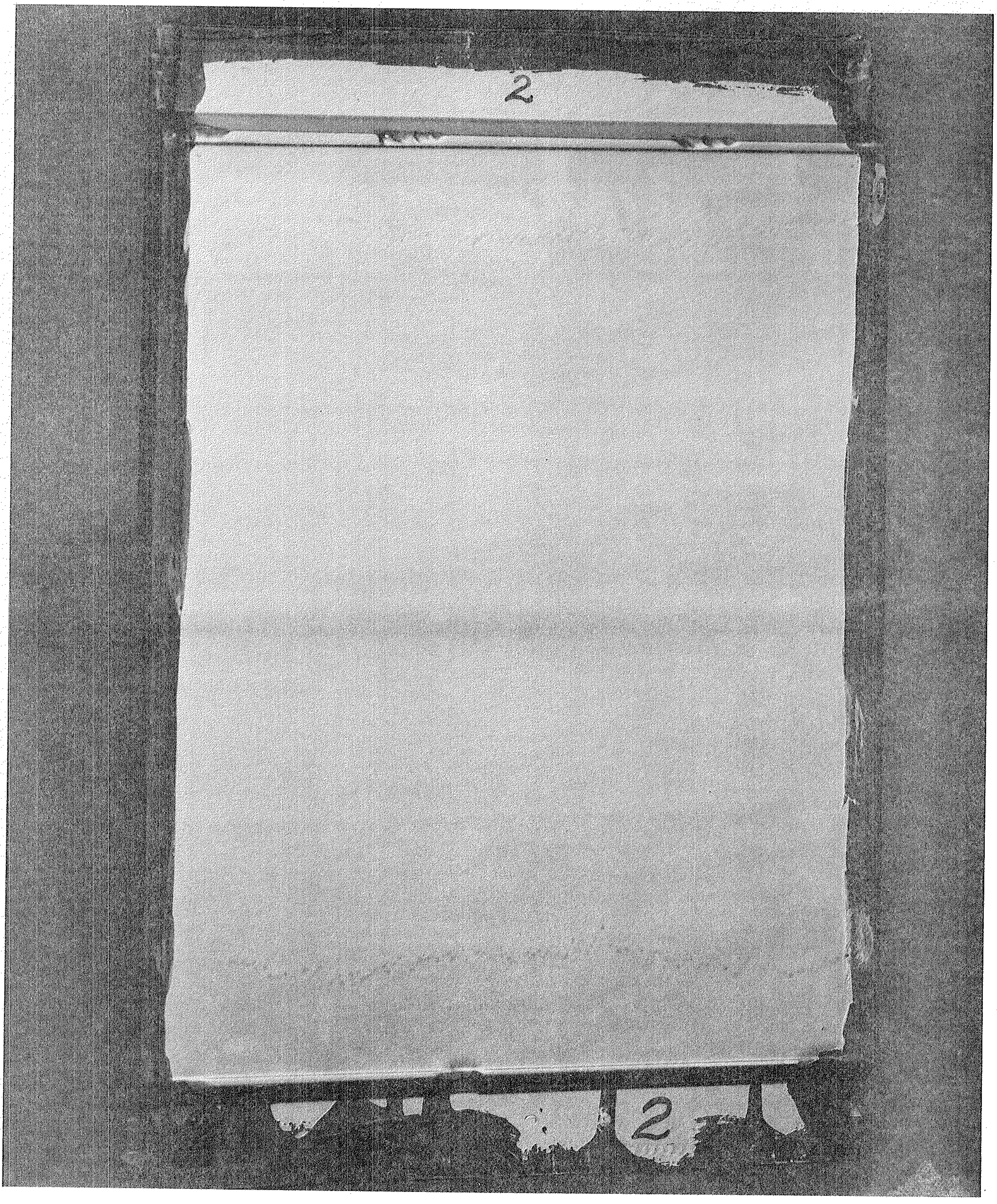


FIGURE 3.1-10 PANEL NO. 2 BOTTOM FACE SHEET AFTER CHEMICAL MILLING

the irregularities and chemical milling to remove approximately .0035 inch of the face sheet thickness. The effects of tool pick-up can be seen after removal of the surface material. It was found that removal of .010 inch of this face sheet thickness was required to eliminate the effects of this severe tool pick-up. The top face sheet was similarly power sanded to remove the irregularities. The effects of these irregularities were removed in the first chemical milling, indicating that little or no tool pick-up was present.

Figures 3.1-11 and 3.1-12 show the bottom and top face sheets, respectively, of Panel No. 3. This panel was formed using the same practices as described, except that the face sheet forming pressure was increased to 100 psi and was applied when the panel temperature indicated 900°F. This change was made to determine the effect on tool pick-up introduced by a change in the progression of face sheet forming. As can be seen, tool pick-up on the bottom face sheet was in a random pattern. No peripheral pick-up occurred. The top face sheet, Figure 3.1-12, was free of surface irregularities. Figure 3.1-13 shows the bottom face sheet after a short immersion in the chemical milling solution. The areas of tool pick-up are heavily smutted, indicating tool material contamination of the titanium.

In fabricating Panel No. 4, the slip sheet material was changed to type 430 stainless steel. This material has a coefficient of expansion more similar to that of titanium than type 321 CRES. This material also has a smoother surface finish than the 2D mill finish of the 321 CRES. Figures 3.1-14 and 3.1-15 show the bottom and top face sheets, respectively, of Panel No. 4. All tool pick-up and surface irregularities have been eliminated.

Panel No. 5 was fabricated using practices identical to those used for Panel No. 4, except that one-half of the bottom type 430 stainless steel slip sheet was power sanded. This was done to determine whether surface smoothness or the coefficient of expansion relationship with titanium had the most to do with resulting panel face sheet smoothness. Figure 3.1-16 shows the bottom face sheet of Panel No. 5. The area showing severe peripheral and random pick-up was formed against the sanded half of the slip sheet; the area formed against the unsanded half of the slip sheet was free of defects.

The next panel of significance was No. 8 which was formed using the same procedures as Panel No. 4, except that the face sheet pressure was increased from 10 psi to 50 psi at 1300°F (same as Panel No. 2). Figure 3.1-17 shows the bottom face sheet of this panel containing severe peripheral and random irregularities.

Panel No. 9 was formed using identical procedures as were used in forming Panel No. 4. Figure 3.1-18 shows the bottom face sheet of the panel containing minor irregularities at the extreme edges. These irregularities were removed by power sanding, and the panel was chemically milled to remove .003 inch from each surface. The sanded irregularities did not smut during chemical milling, indicating that no tooling material pick-up was present.

3.2 ESTABLISHMENT OF FORMING AND BONDING PARAMETERS

A panel was formed to establish forming and bonding parameters for fabrication of the large demonstration panels. This panel duplicated the geometry of the large panels in height, web spacing, and material thickness. This panel was formed against type 321 stainless steel slip sheets due to temporary unvailability of the 430 stainless steel. A small amount of graphite (5% by volume) was added to the boron nitride-binder-acetone solution. The solution

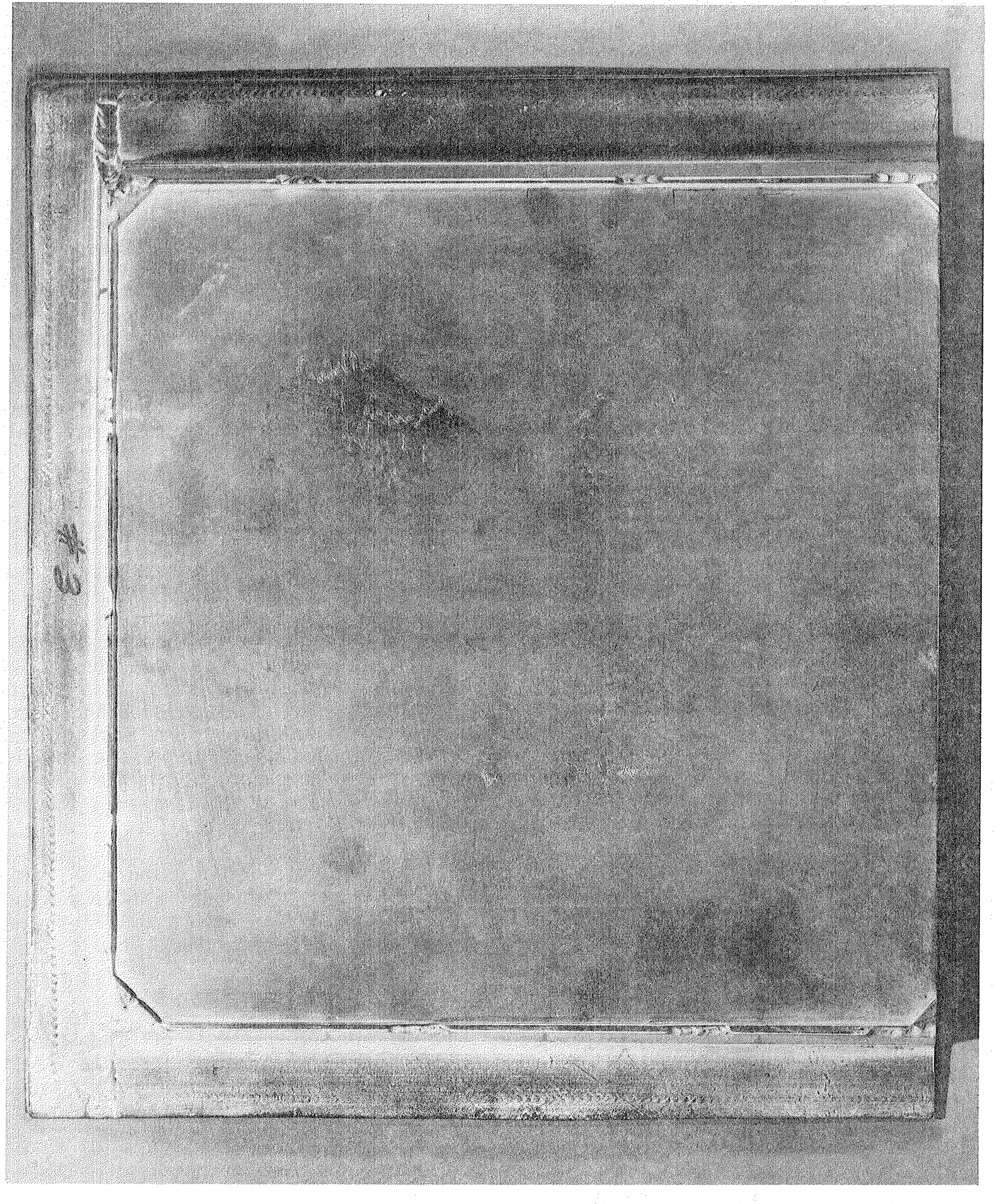


FIGURE 3.1-11 PANEL NO. 3 BOTTOM FACE SHEET

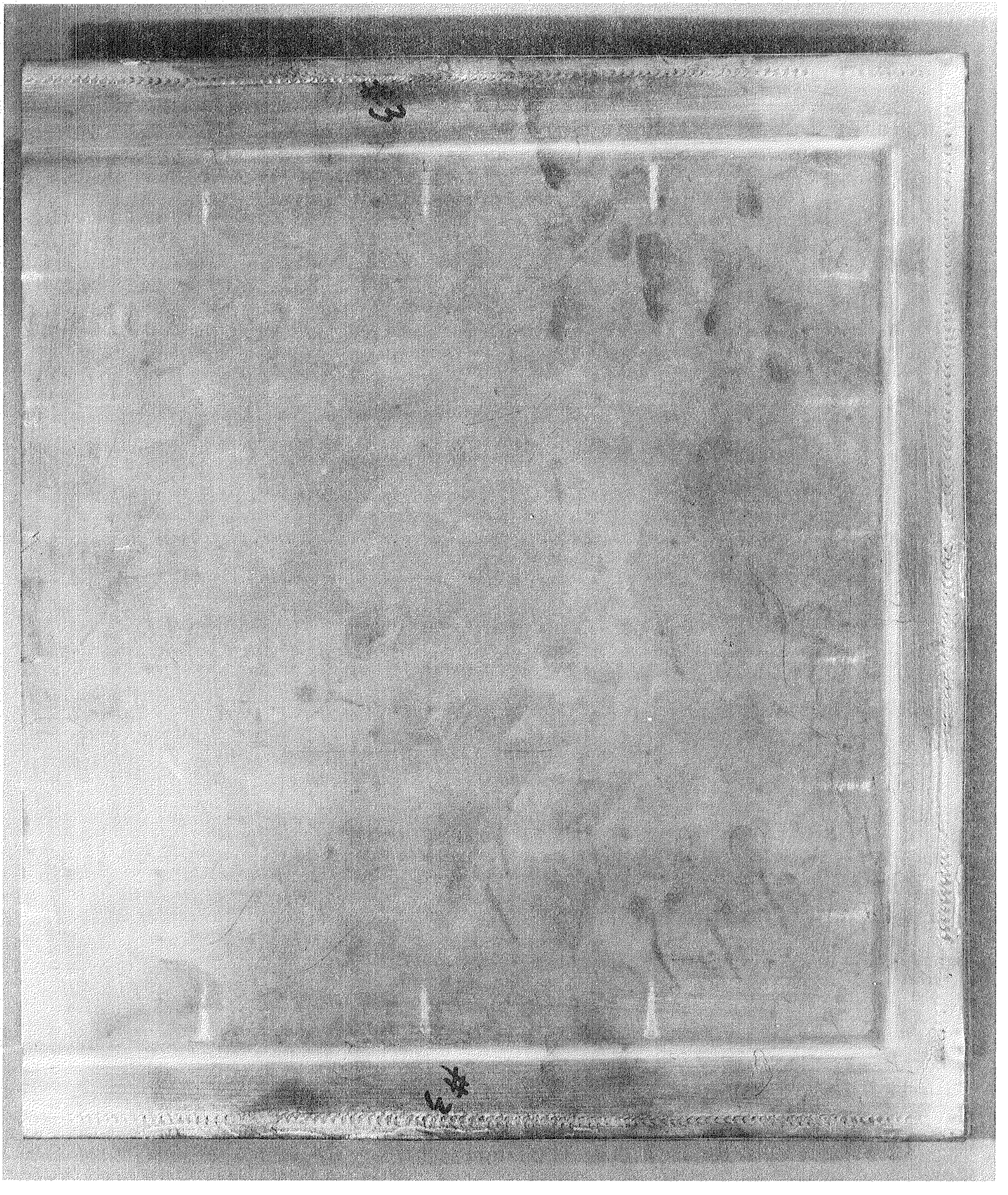


FIGURE 3.1-12 PANEL NO. 3 TOP FACE SHEET

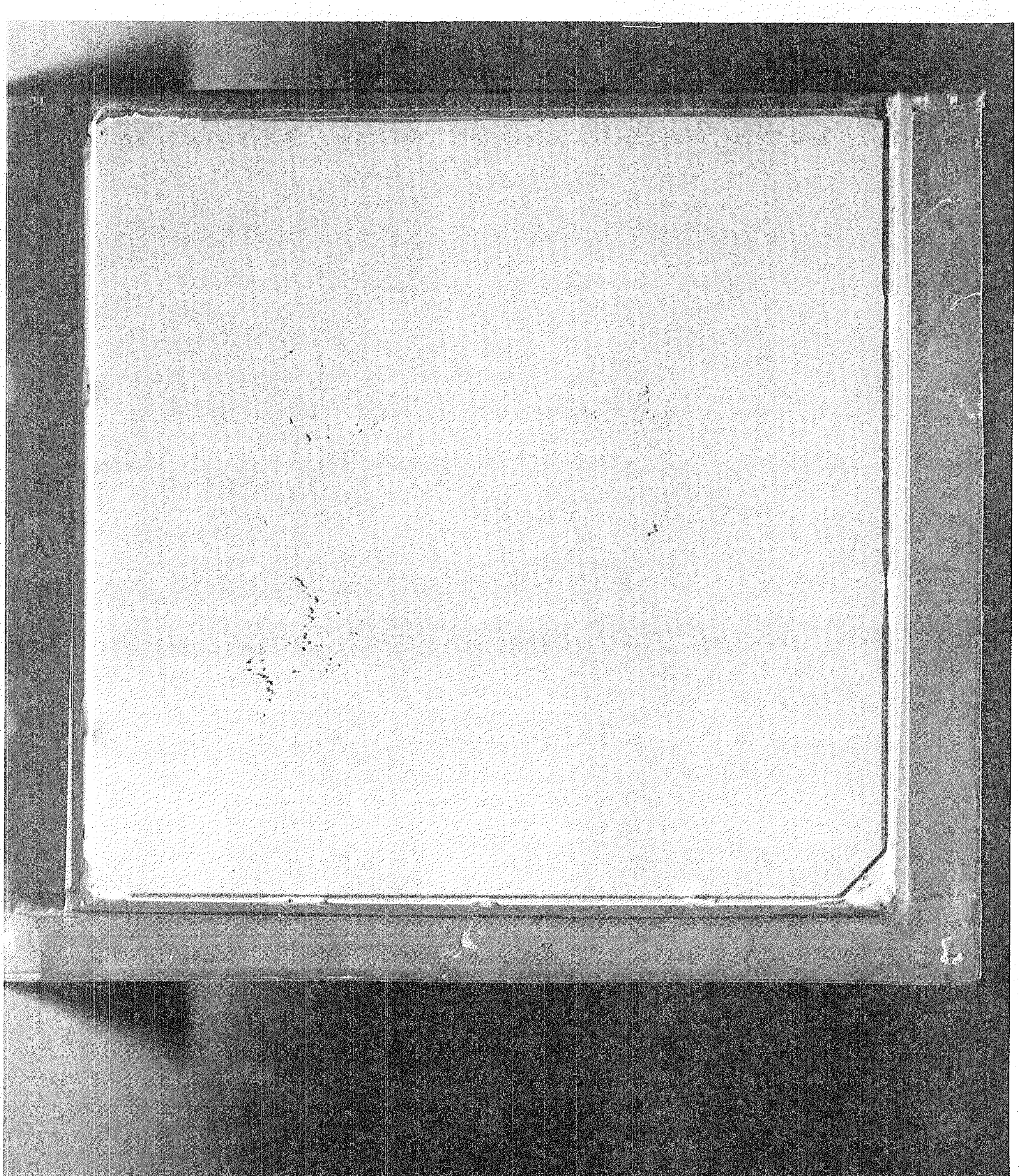


FIGURE 3.1-13 PANEL NO. 3 TOP FACE SHEET AFTER CHEMICAL MILLING

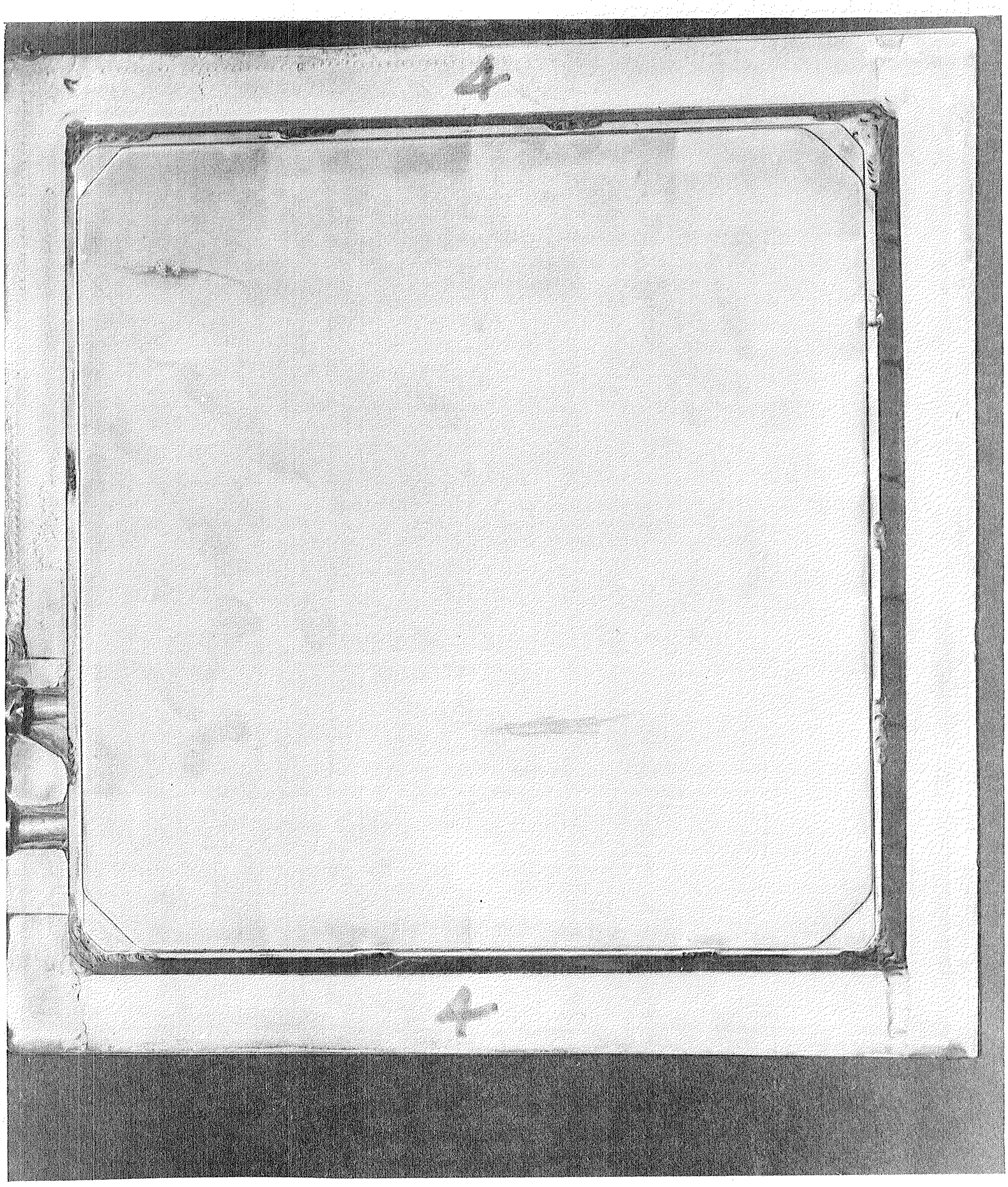


FIGURE 3.1-14 PANEL NO. 4 BOTTOM FACE SHEET

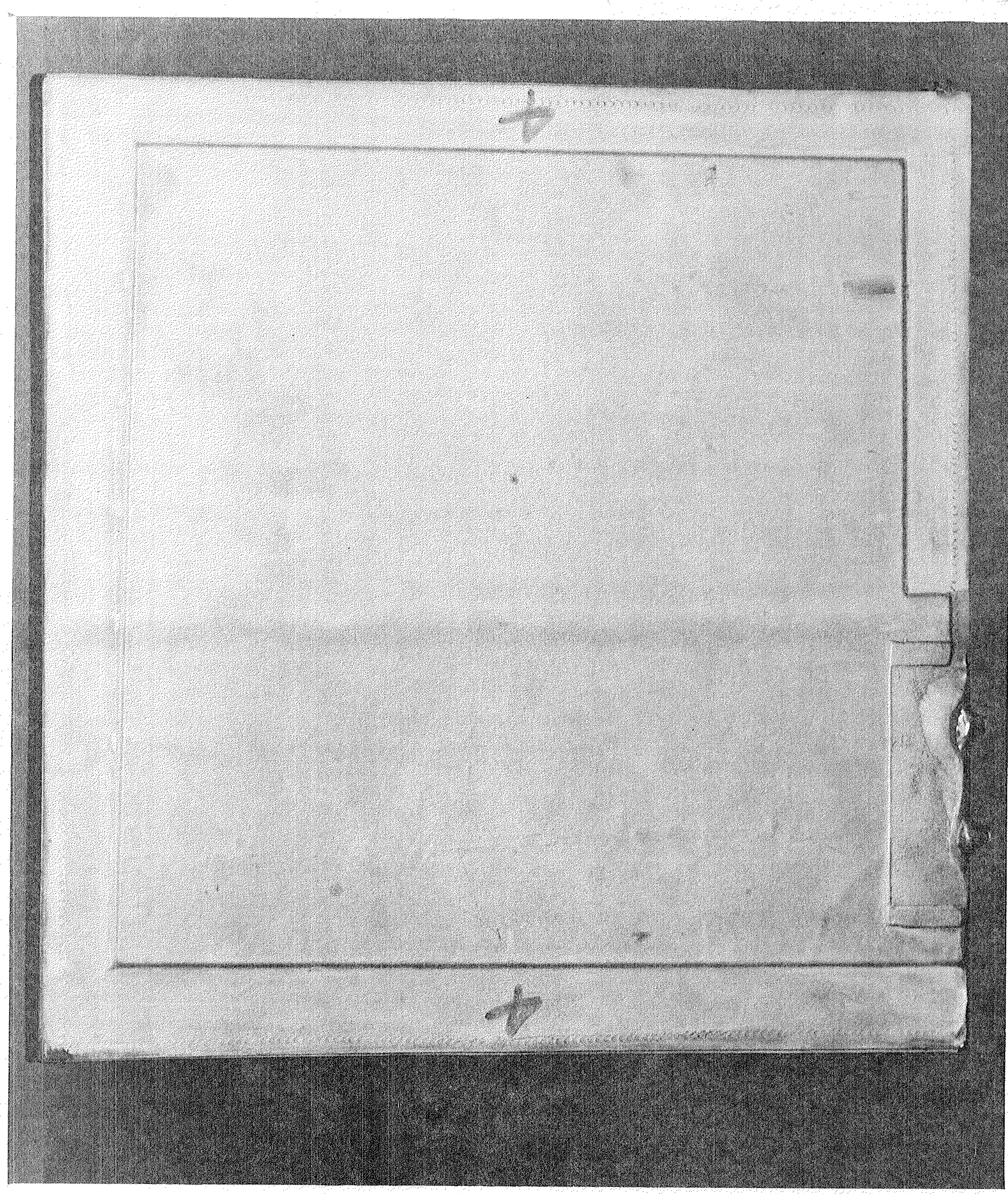


FIGURE 3.1-15 PANEL NO. 4 TOP FACE SHEET

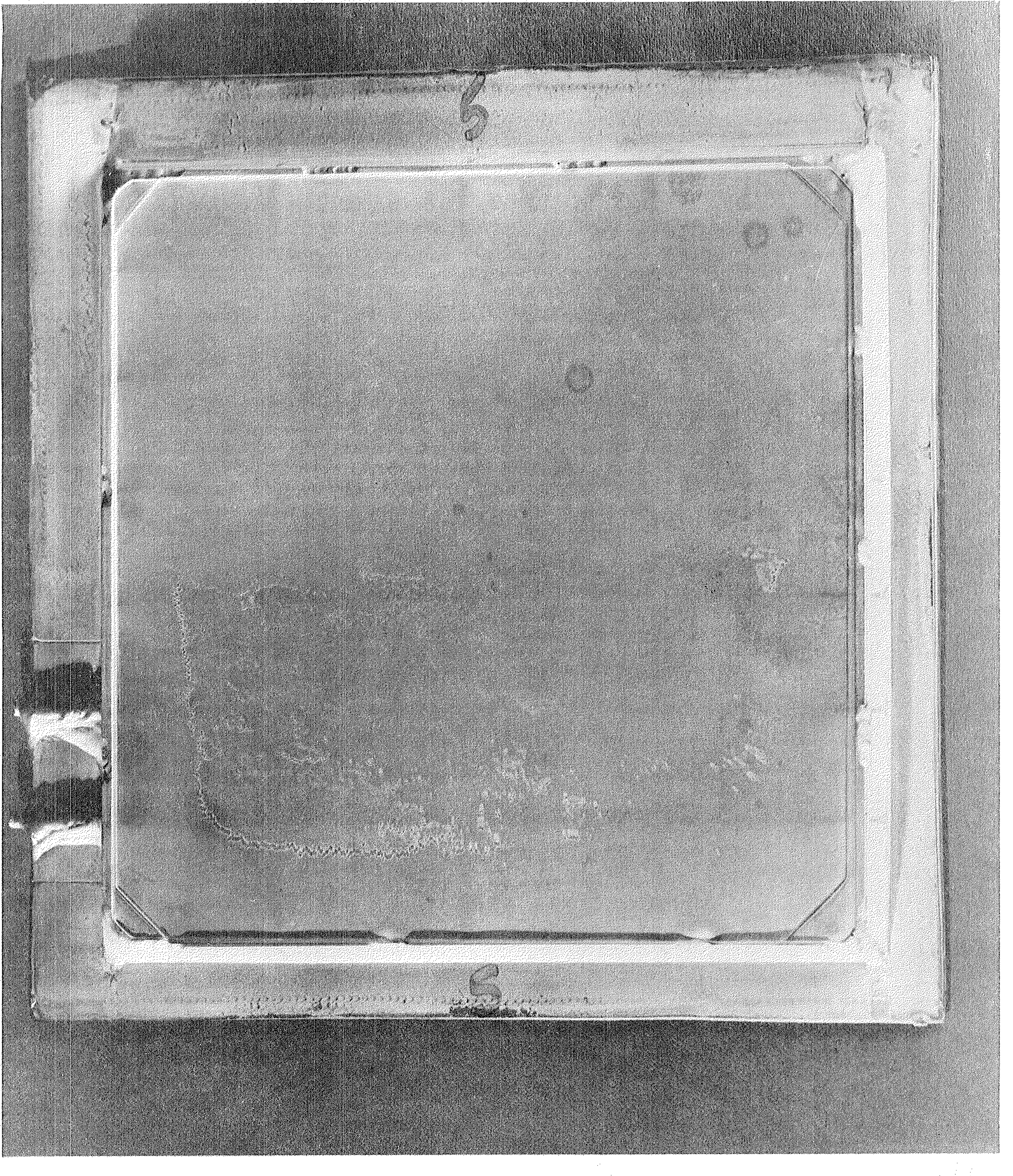


FIGURE 3.1-16 PANEL NO. 5 BOTTOM FACE SHEET

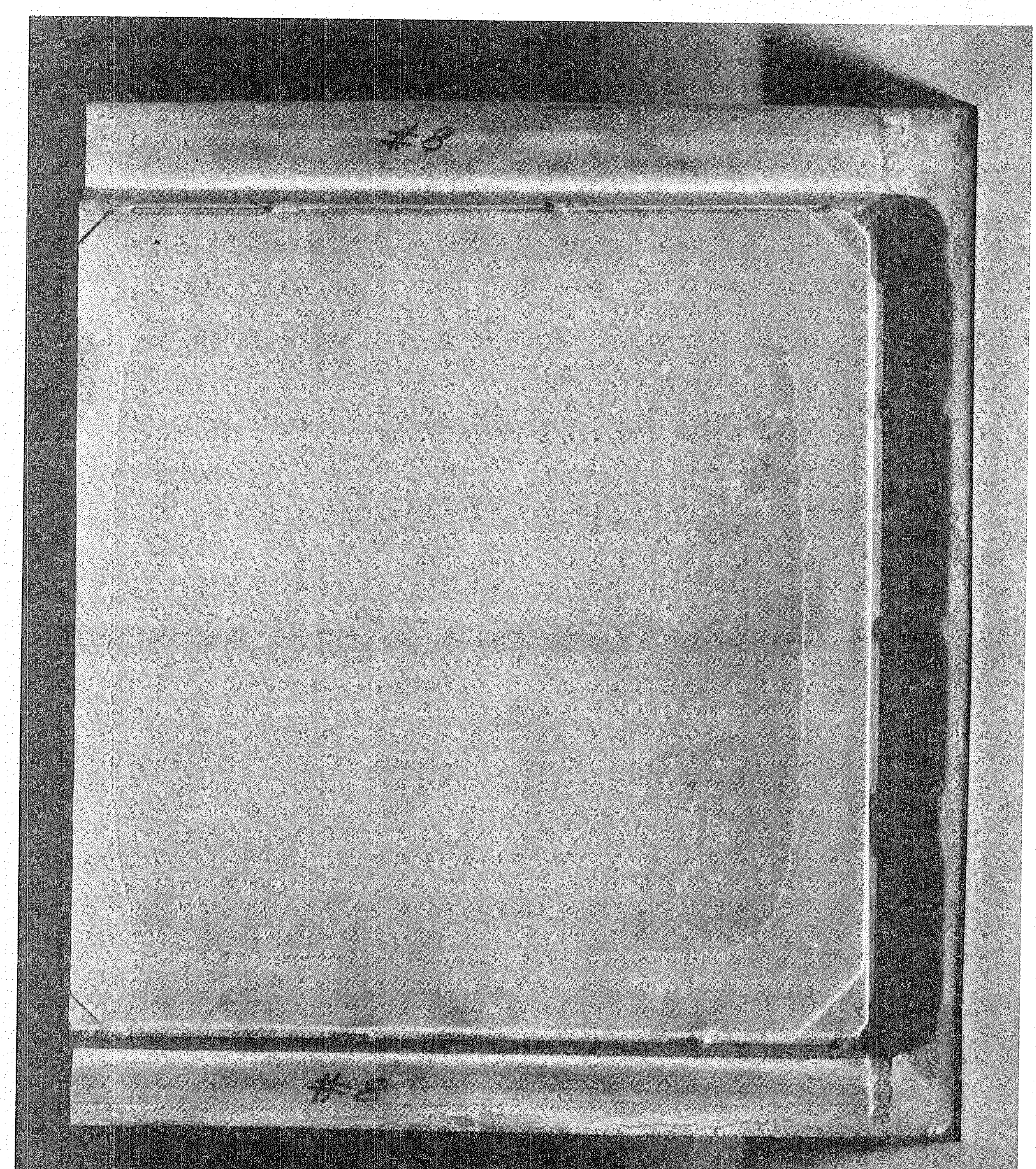


FIGURE 3.1-17 PANEL NO. 8 BOTTOM FACE SHEET

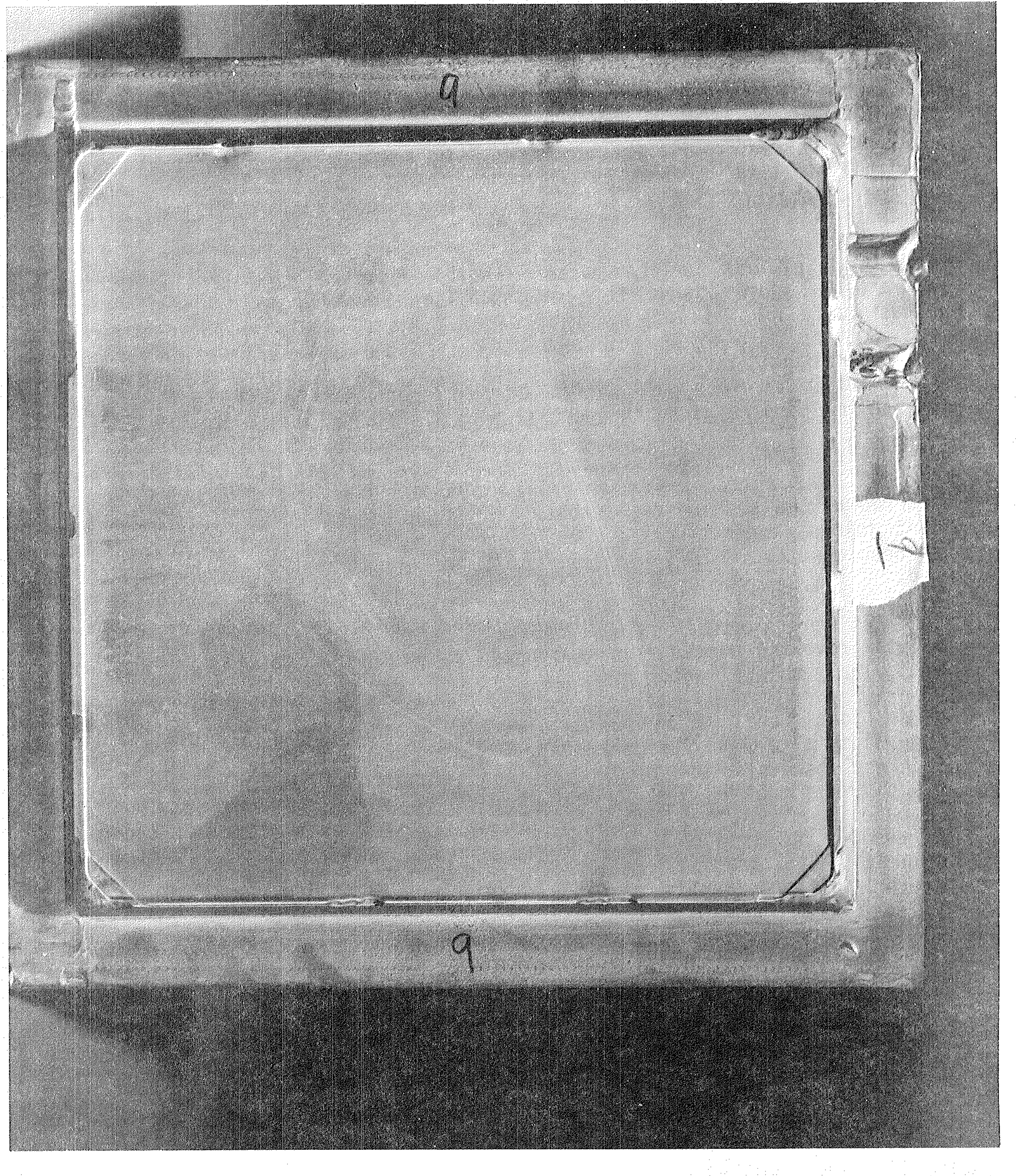


FIGURE 3.1-18 PANEL NO. 9 BOTTOM FACE SHEET

was applied to the external face sheet surfaces and to the slip sheets. This panel, shown in Figure 3.2.1, was free from tooling mterial pick-up or irregularities which were typical of previous panels formed against type 321 stainless steel.

This panel was conditioned in preparation for chemical milling by immersion in a hot Kolene salt bath per DPS 9.29. Prior practice has been to abrasively blast the exterior surfaces. After the Kolene treatment, the panel was chemically milled to remove approximately 0.003 inch material from each surface. Complete removal of the white layer was confirmed by metallurgical examination.

Bend tests of the surface material were conducted to determine ductility. Figure 3.2-2 shows these bend tests. The specimens on the left show the radius at failure of the top face sheet. Those specimens adjacent are also from the top face sheet but were bent with the side exposed to argon only (inside of panel) on the outside of the bend. The specimens to the right are from the bottom face sheet. It can be seen that removal of material by chemical milling restored the ductility of the face sheets.

Surface roughness measurements were taken on the panel after chemical milling. The surfaces measured 45 to 72 microinches. The higher readings occurred as the sensing unit crossed the face sheets at the internal web-face sheet joints, indicating a slight depression in these areas. This condition has been observed in prior panel fabrication where thin face sheets have been used.

Specimens were excised from this panel for metallurgical examination. This analysis revealed poor diffusion bonding between the core and the face sheets, particularly on the bottom side.

An additional panel was run using a revised pressure cycle designed to improve the quality of the diffusion bonding. This panel was formed against type 321 stainless steel slip sheets with the addition of graphite in the boron nitride solution, duplicating the conditions present in forming the previous panel. The panel surfaces were characterized by severe tooling pick-up, contrary to the results obtained on the previous panel. The reason for this anomoly is unknown. Metallurgical examination of specimens excised from this panel revealed no improvement in the diffusion bond quality.

It was concluded that the mill heat of material being used was difficult to diffusion bond under normal parameters of time, temperature, and pressure. From prior experience with a similar diffusion bonding problem, it was decided to run the next panel at a higher temperature during the diffusion bonding portion of the fabrication cycle.

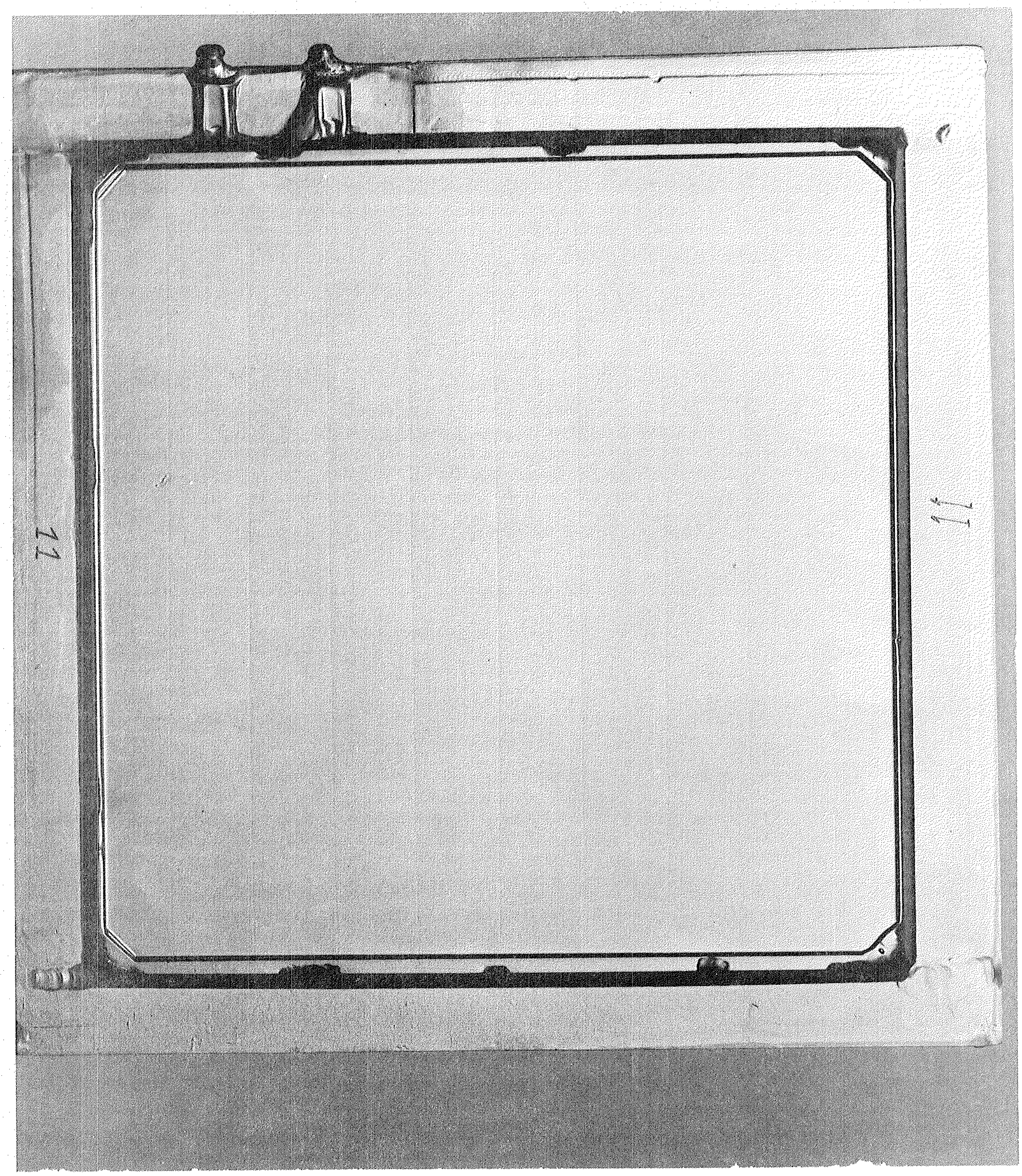


FIGURE 3.2-1 SMALL PARAMETERS PANELS

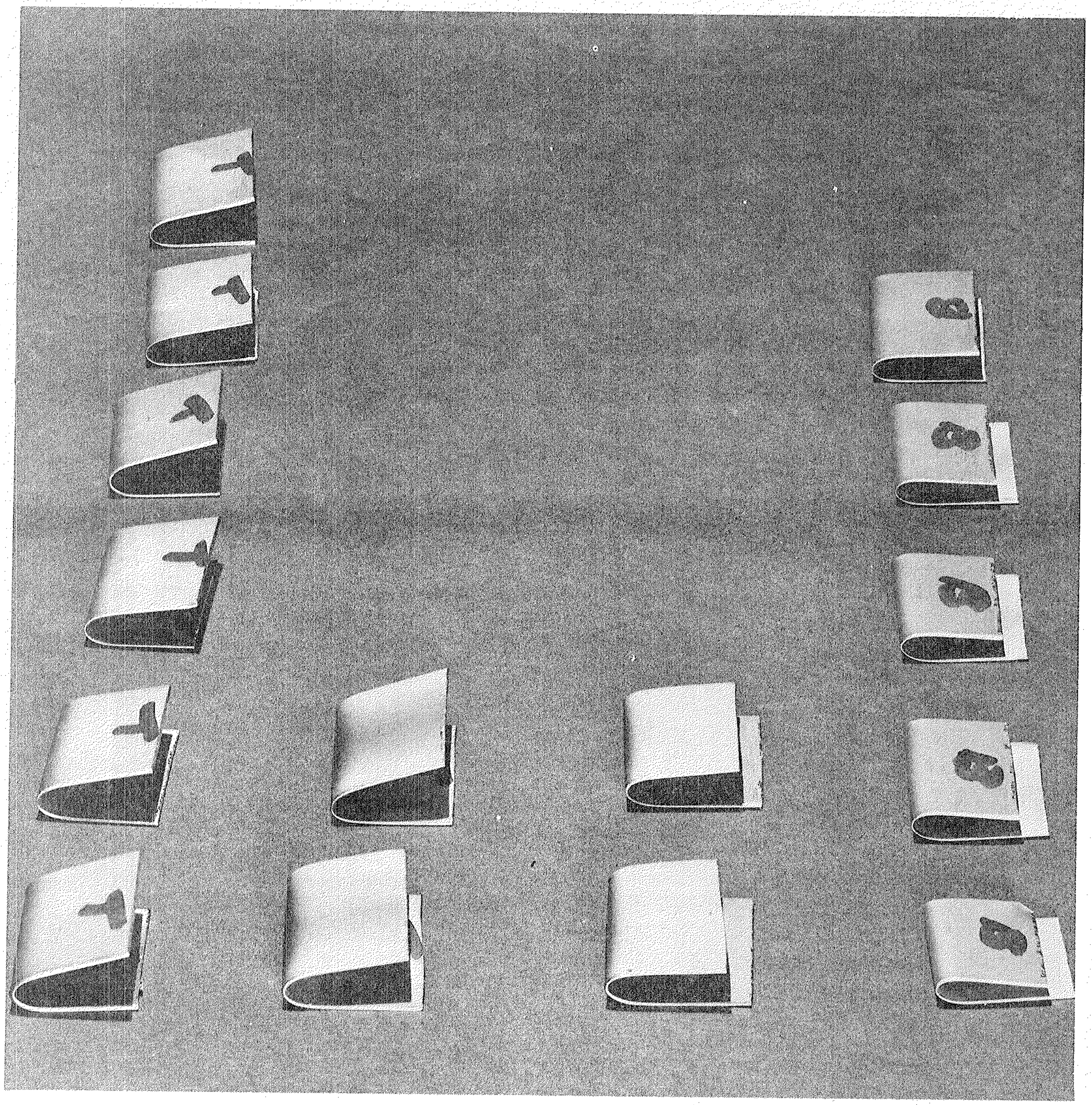


FIGURE 3.2-2 BEND TESTS FROM SMALL PANEL

4.0 LARGE PANEL FABRICATION

4.1 SMOOTH PANEL

The first large panel was formed against type 430 stainless steel using the established pressure cycle. The temperature was increased to 1720°F during the diffusion bonding portion of the cycle. Metallurgical examination of this panel revealed excellent diffusion bonding. This panel was unacceptable, however, due to an equipment malfunction which caused a momentary reduction in press pressure during a period of high forming pressure. This resulted in a slight increase in the panel height during this period. When the full press pressure was restored, core crushing occurred in approximately one-half of the panel. A second panel was prepared and formed using the same parameters as described. A leak developed during this run in the bladder which provides press pressure. This resulted in a slight expansion in the height of the panel. The expansion was not of sufficient duration to cause core crushing when the press pressure was restored. Depressions were created at each web location, however, which ranged foom 0.002 to 0.006 inch in depth. A section of this panel was metallurgically examined and revealed excellent diffusion bond quality.

Forming of the third large panel was unsuccessful due to an equipment failure. This panel suffered core rupture early in the forming cycle. Subsequent investigation revealed that the panel was overheated at one edge, causing partial transformation of the titanium material to the beta phase. Several ruptures were discovered in this area adjacent to spot welds. It is believed that the partial transformation of the material reduced its superplasticity, and overload failure occured in the areas of maximum strain. The platen heaters were examined, and it was found that a heater failure had occurred. The platen heaters are in a series-parallel circuit, and one heater strip had separated in the leg under the platen edge. Ironically, this failed strip had contacted and fused to a strip in the adjacent heater leg, compounding the heater imbalance. The net result was nonuniform current density in the heater, resulting in over temperature along the edge containing fewer strips, which was not reflected in the control thermocouple located in he center of the platen, an area of lower current density.

The platen heaters were replaced, and a fourth panel was formed. Figure 4.1-1 shows the panel as it was removed from the retort. The panel surfaces were smooth with no tooling pick-up. This panel was chemically milled and cut to size. Specimens were excised from the edges of the panel and metallurgically examined. The diffusion bond quality was found to be excellent and is shown in Figures 4.1-2 through 4.1-5. Forming of the core-to-face sheet intersections and around the spot welds on the bottom side of the panel was found to be extremely tight. This forming was not as tight on the top side, indicating that gas entrapment occurred in the face sheet cavity during the diffusion bonding cycle. Figure 4.1-6 is a cross section showing the internal core configuration. Figure 4.1-7 shows a positive of an x-ray exposure showing the internal structure of the panel. Figures 4.1-8 and 4.1-9 show the top and bottom surfaces respectively of this panel after chemical milling and trimming to size. Slight face sheet grooves occurred at each core-to-face sheet intersection. The maximum depth of these grooves was measured to be 0.0015 inch on the top side and 0.0025 inch on the bottom side of the panel. Face sheet grooves such as these are not inherent in the process, but are apt

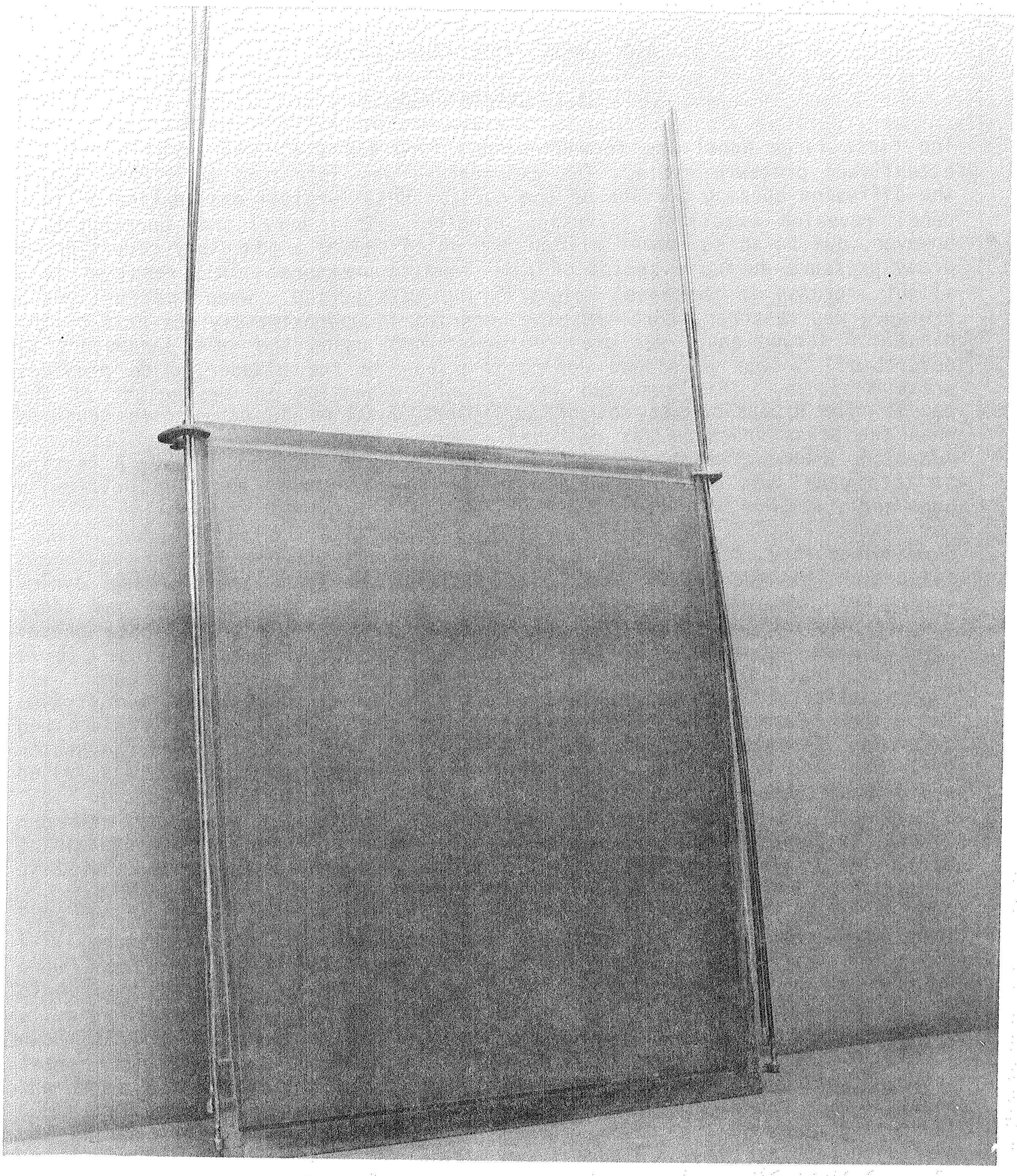
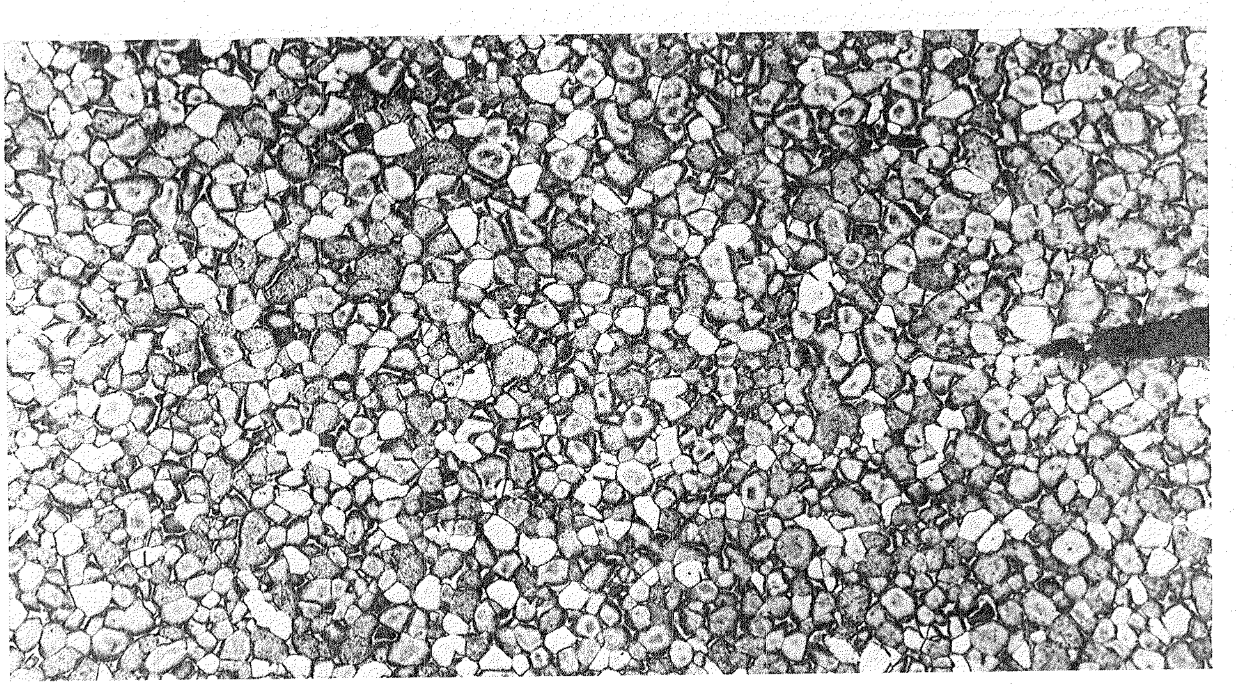


FIGURE 4.1-1 PANEL AFTER REMOVAL FROM RETORT

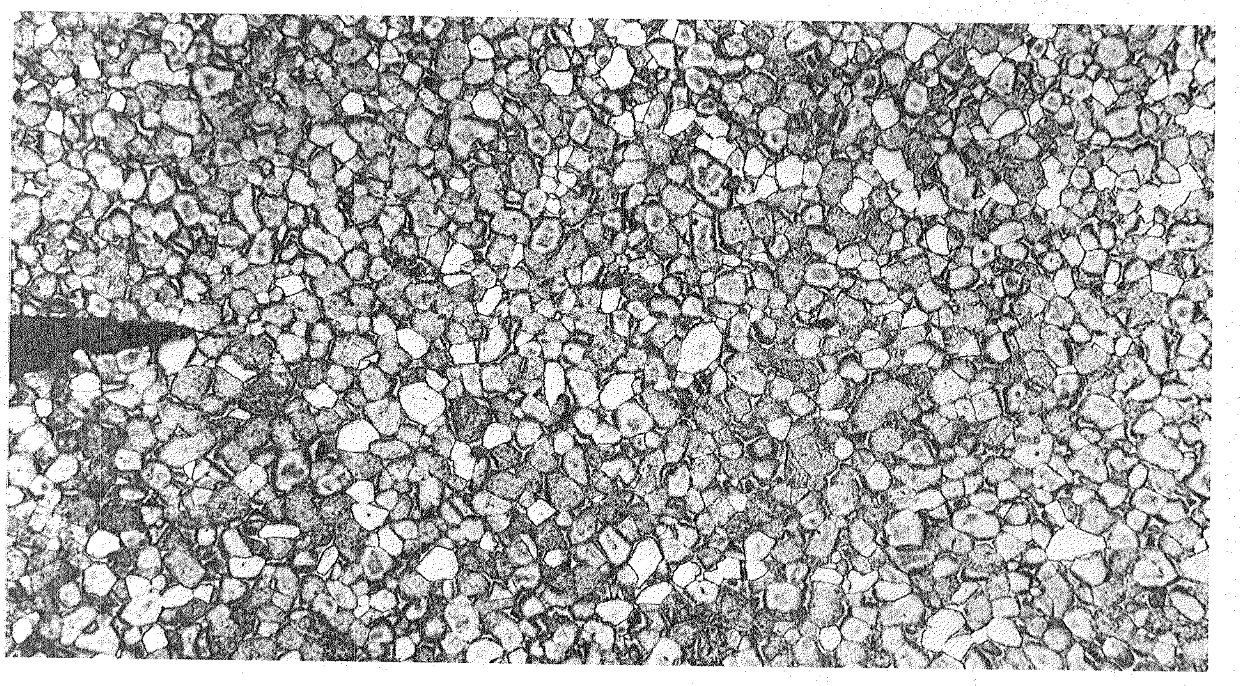


NEG. LW-525 MAG.300X

FIGURE 4.1-2 MICROSTRUCTURE AT TOP CORE-TO-FACE SHEET INTERFACE

NEG. LW-524 MAG. 300X

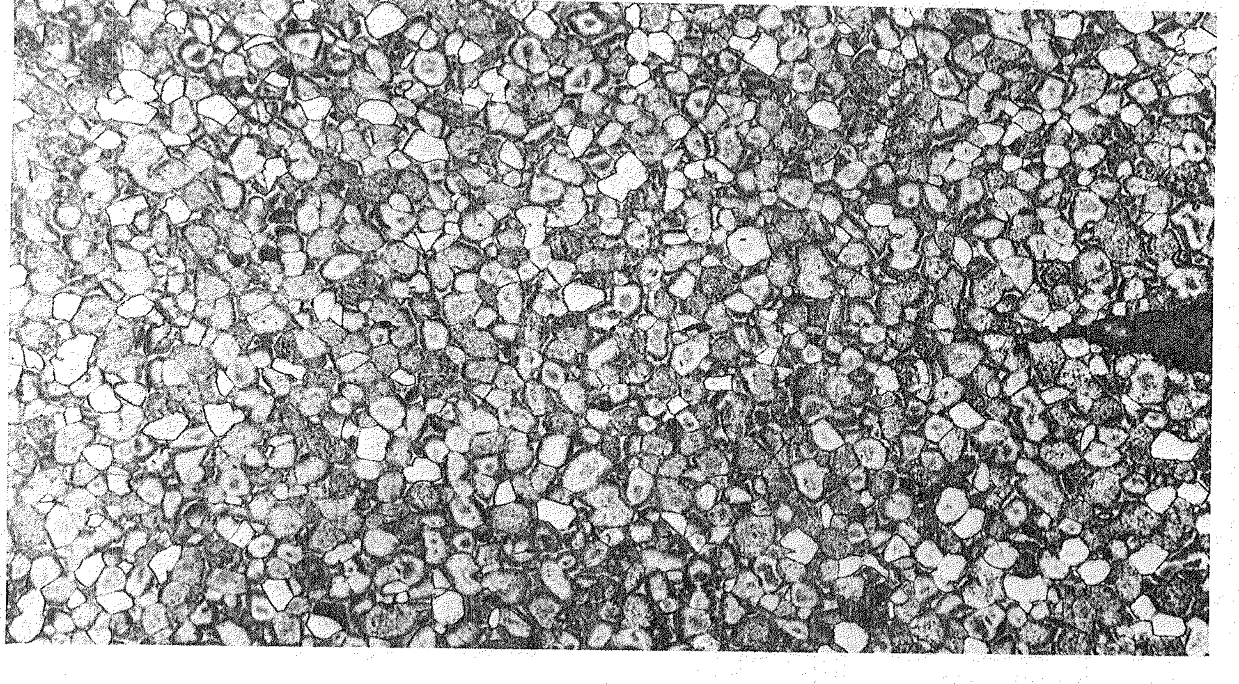
FIGURE 4.1-3 MICROSTRUCTURE AT TOP CORE INTERFACE



NEG. LW-527

MAG. 300X

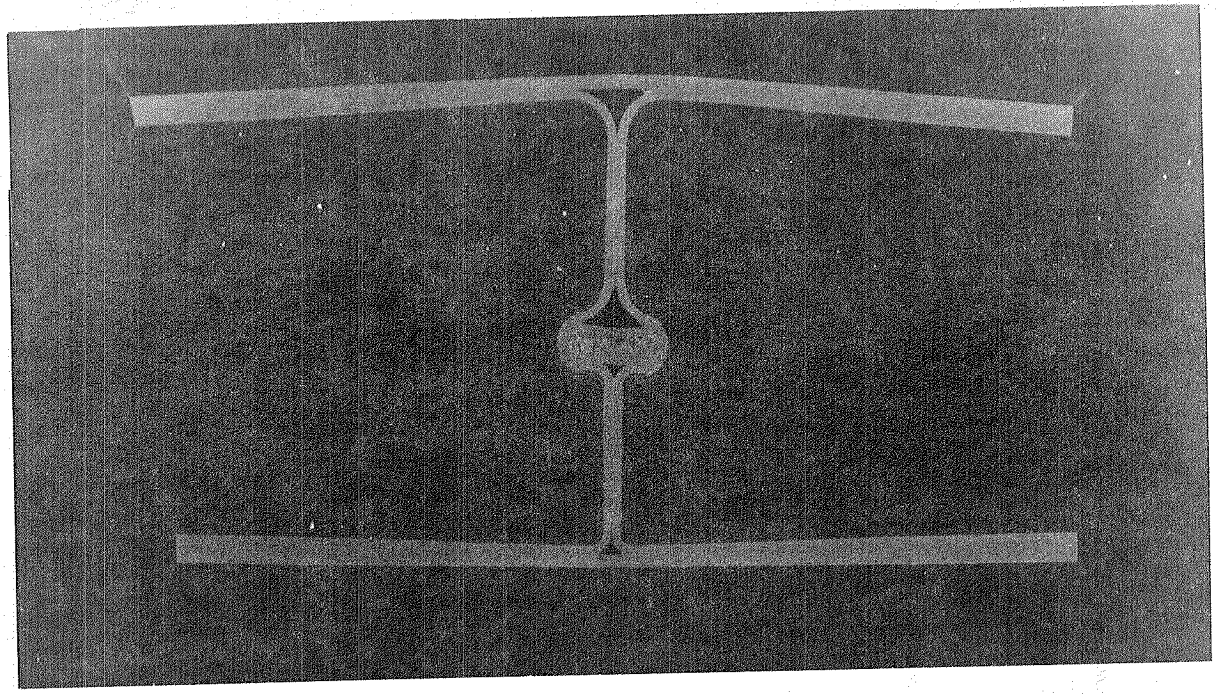
FIGURE 4.1-4 MICROSTRUCTURE AT BOTTOM CORE-TO-FACE SHEET INTERFACE



NEG. LW-526

MAG. 300X

FIGURE 4.1-5 MICROSTRUCTURE AT BOTTOM CORE INTERFACE



NEG. LW-519 MAG. 7X

FIGURE 4.1-6 CROSS SECTION FROM FLAT PANEL

(Note: Face sheets were deformed during mounting.)

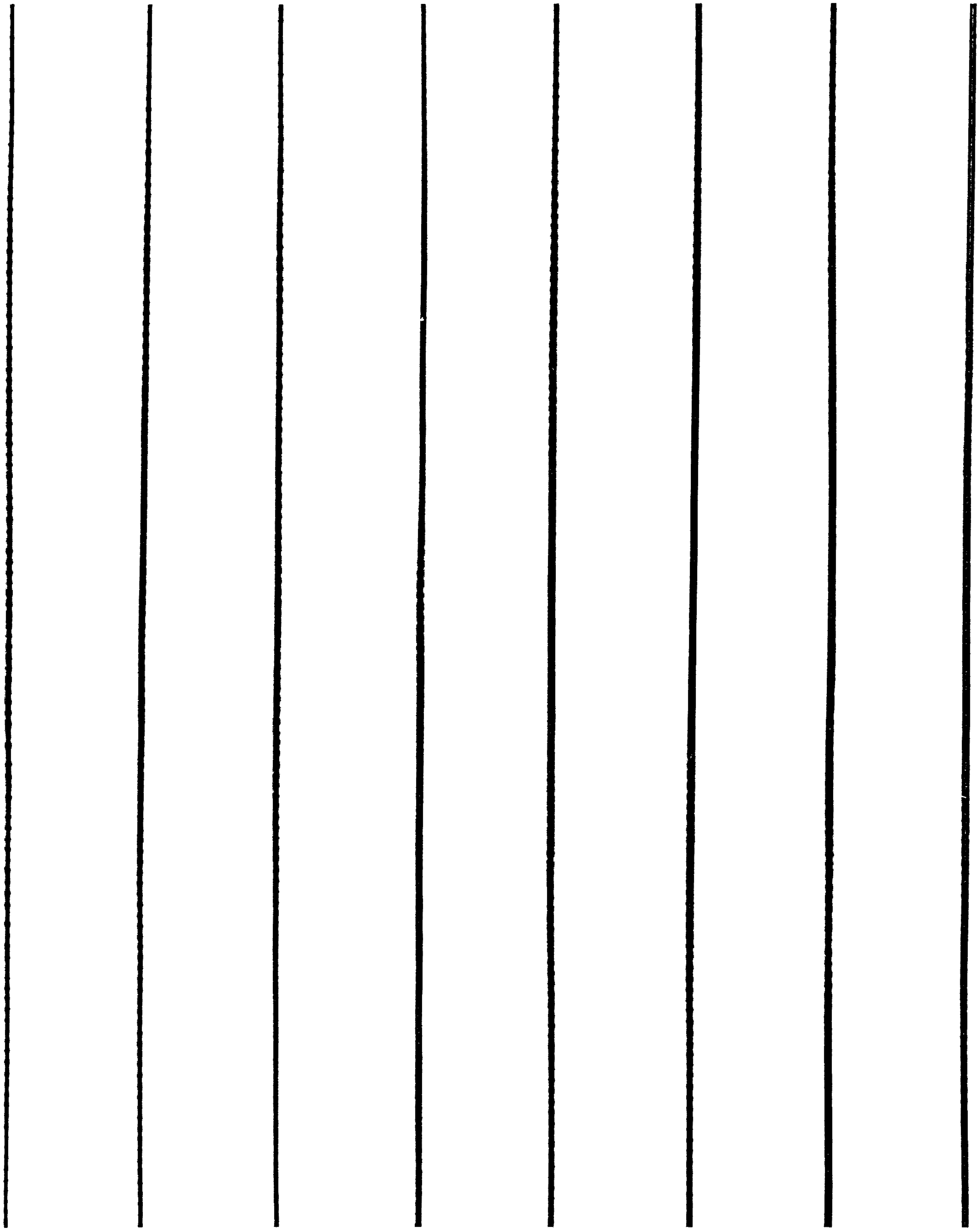


FIGURE 4.1-7 X-RAY EXPOSURE OF PANEL SHOWING WEBS

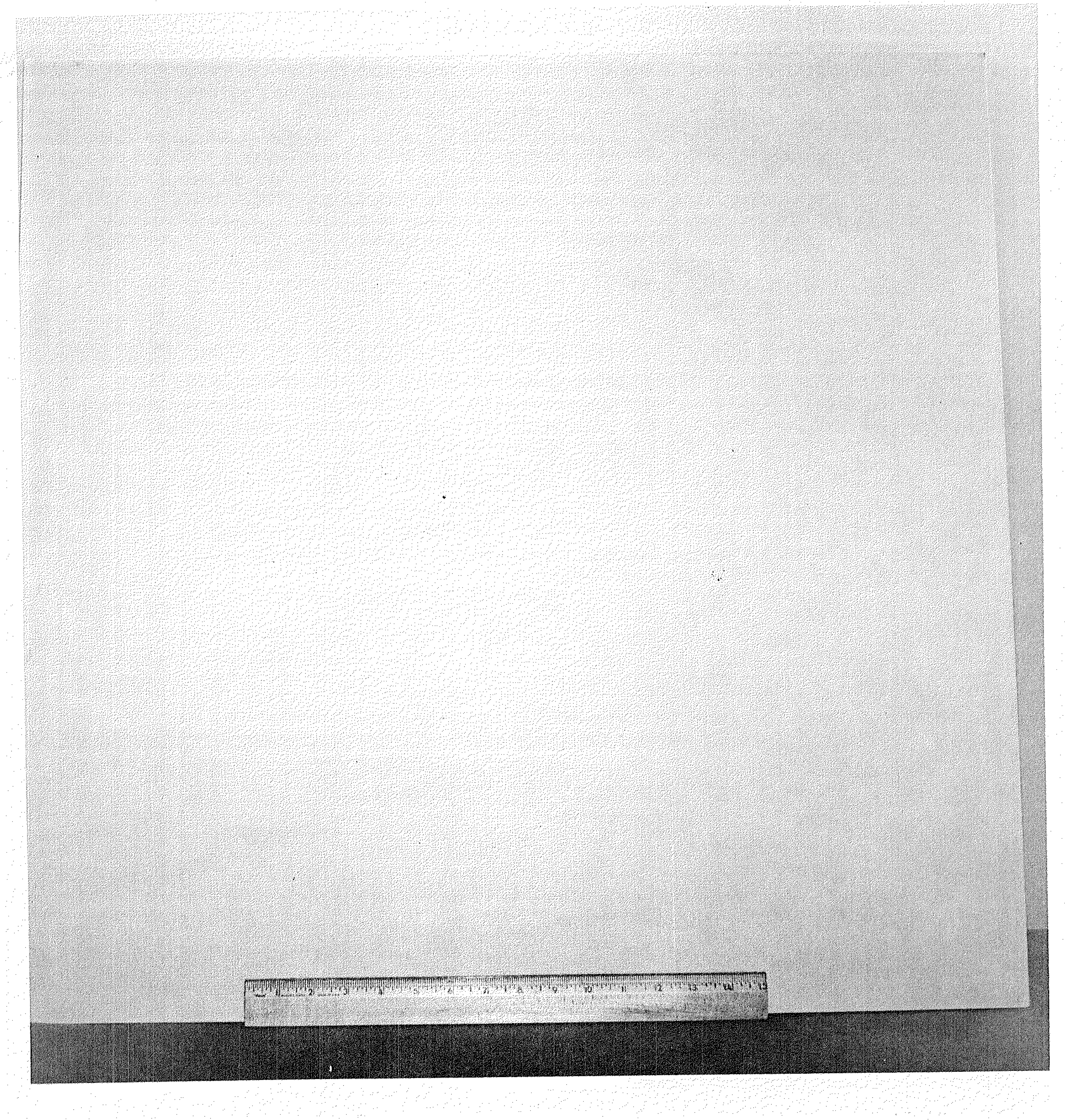


FIGURE 4.1-8 TOP SIDE OF PANEL NO. 4

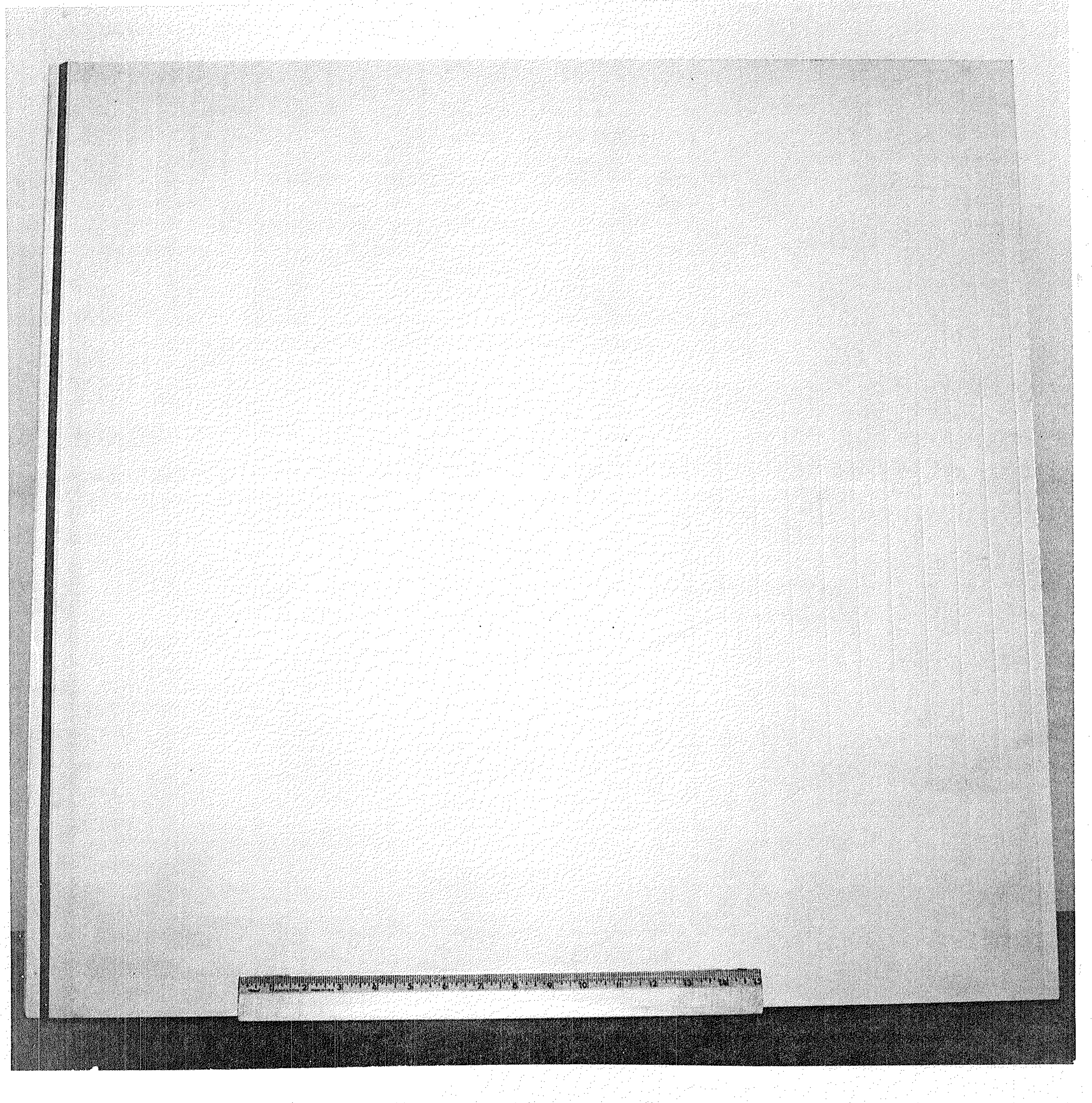


FIGURE 4.1-9 BOTTOM SIDE OF PANEL NO. 4

to result on panels with thin face sheets, i.e., less than 0.025 inch. The problem relates to the balance between the core forming pressure and the face sheet pressure during the final stages of core forming.

Normal practice has been to reduce the face sheet pressure to 10 psi at the beginning of the diffusion bonding cycle. When core forming is not virtually complete at this point and the face sheets are thin, the expanding core gathers the face sheet, resulting in face sheet grooving. The solution is to maintain a higher face sheet pressure to restrain gathering until core forming is complete.

The panel height was measured after trimming. These measurements showed that the panel height was greater in the center of the panel as shown in Figure 4.1-10. It is believed that these measurements reflect structural deflection in the restraining fixture which occurs under forming and diffusion bonding pressure loads.

4.2 LFC CONFIGURATED PANEL

4.2.1 PANEL FABRICATION

Figure 4.2-1 shows a cross section of the design for the LFC configurated panel. Special tooling required to fabricate this panel consisted of metal strips, 0.100 inch thick by 0.56 inch wide, sufficiently long to extend the entire length of the panel. Holes, 0.240 inch in diameter, were drilled on one-half inch centers in these strips.

The tooling strips were attached to the panel prior to forming so that the panel surfaces would form over the strips, into the holes, and out to the restraint tooling between the strips. The welded core envelope was positioned so that the expanded cell walls would be located in the full panel height land areas between the tooling strips.

Figure 4.2-2 shows the lay-up of the first LFC configurated panel in the forming retort. During forming of this panel, a higher face sheet pressure was maintained during the diffusion bonding portion of the fabrication cycle to eliminate face sheet grooving. The panel surfaces were smooth with no tooling pick-up. Figures 4.2-3 and 4.2-4 show the top and bottom surfaces, respectively, of this panel after Kolene treatment and chemical milling. A cut was made in this panel transverse to the webs to examine the core configuration. It was revealed that face sheet gas entrapment had occurred on the bottom side as shown in the cross sectional view presented in Figure 4.2-5. The top side was fully formed. The amount of separation of the bottom webs indicated that gas entrapment had occurred early in the forming cycle.

A second panel was prepared and formed using a revised method for exhausting the face sheet forming gas. This panel was radiographically inspected for determination of core forming prior to chemical milling. Figure 4.2-6 shows a positive of an X-ray exposure taken from a typical area of the panel. The webs appear to be fairly well oriented relative to the perforated strips in most areas of the panel. This panel was Kolene treated and chemically milled. The surfaces were smooth with no tooling pick-up. A cut was made in this panel transverse to the webs to examine the core configuration. Figure 4.2-7 shows a cross section of this panel. Face sheet forming gas entrapment occurred on both the top and bottom sides of this panel late in the forming cycle as reflected in the wide cleavage at the core-to-face sheet interfaces and at the spot welds.

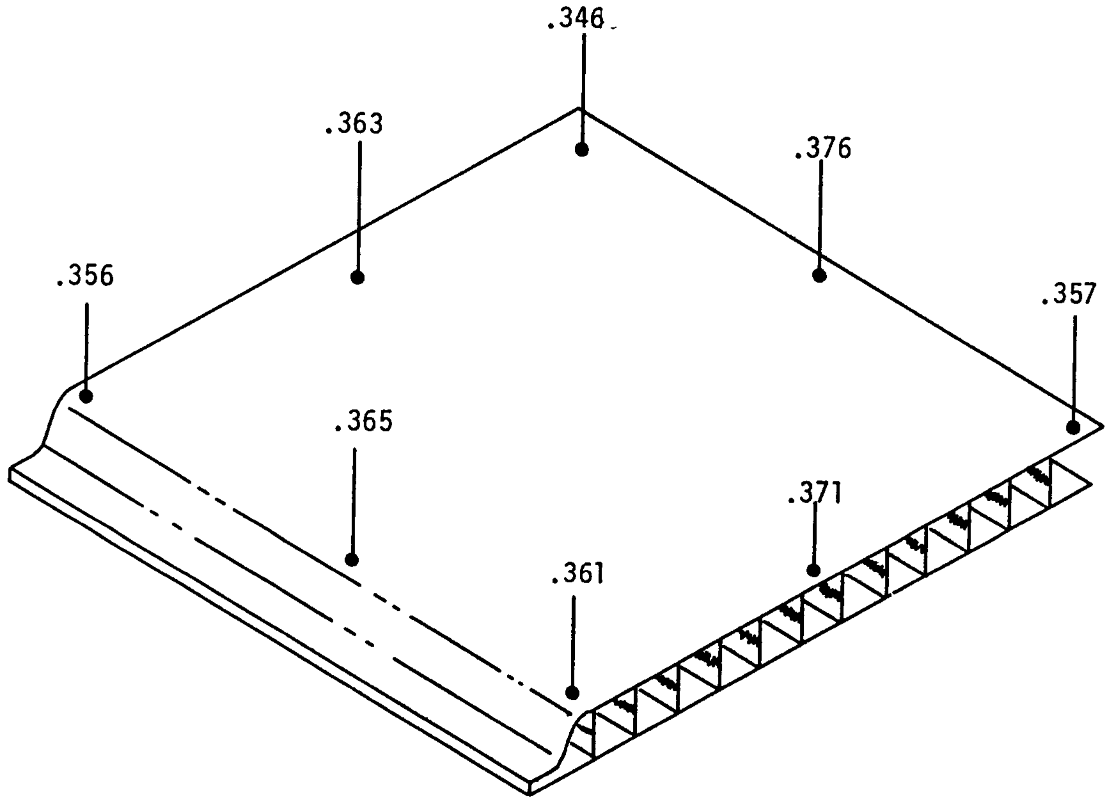


FIGURE 4.1-10 PANEL HEIGHT MEASUREMENTS

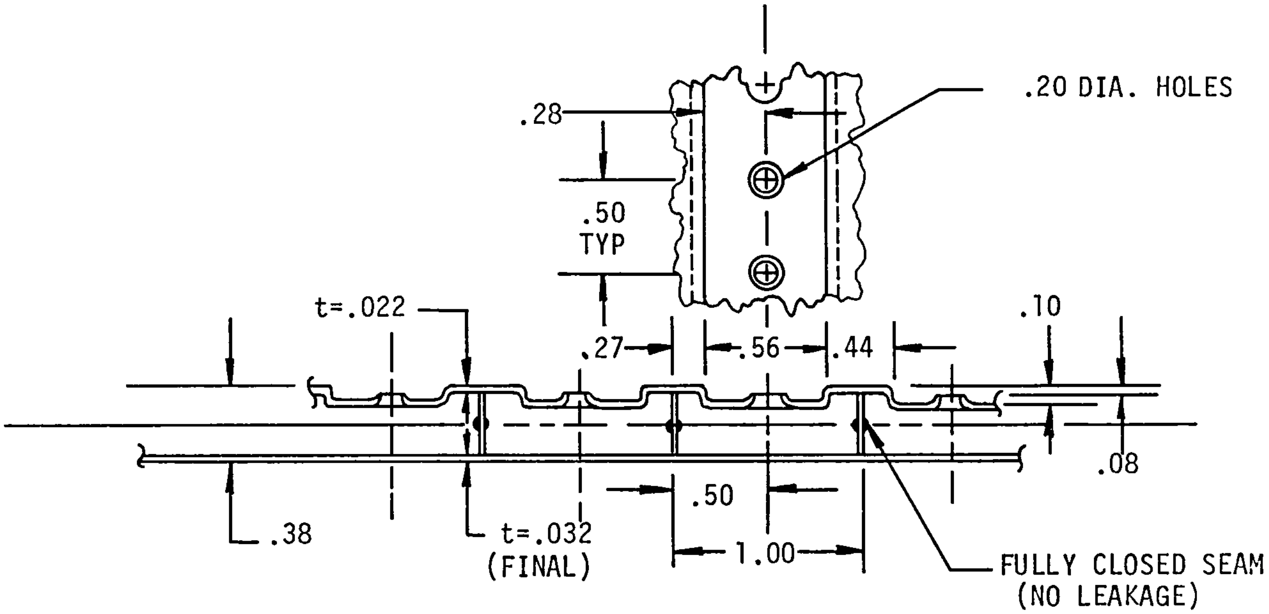


FIGURE 4.2-1 LFC PANEL DESIGN

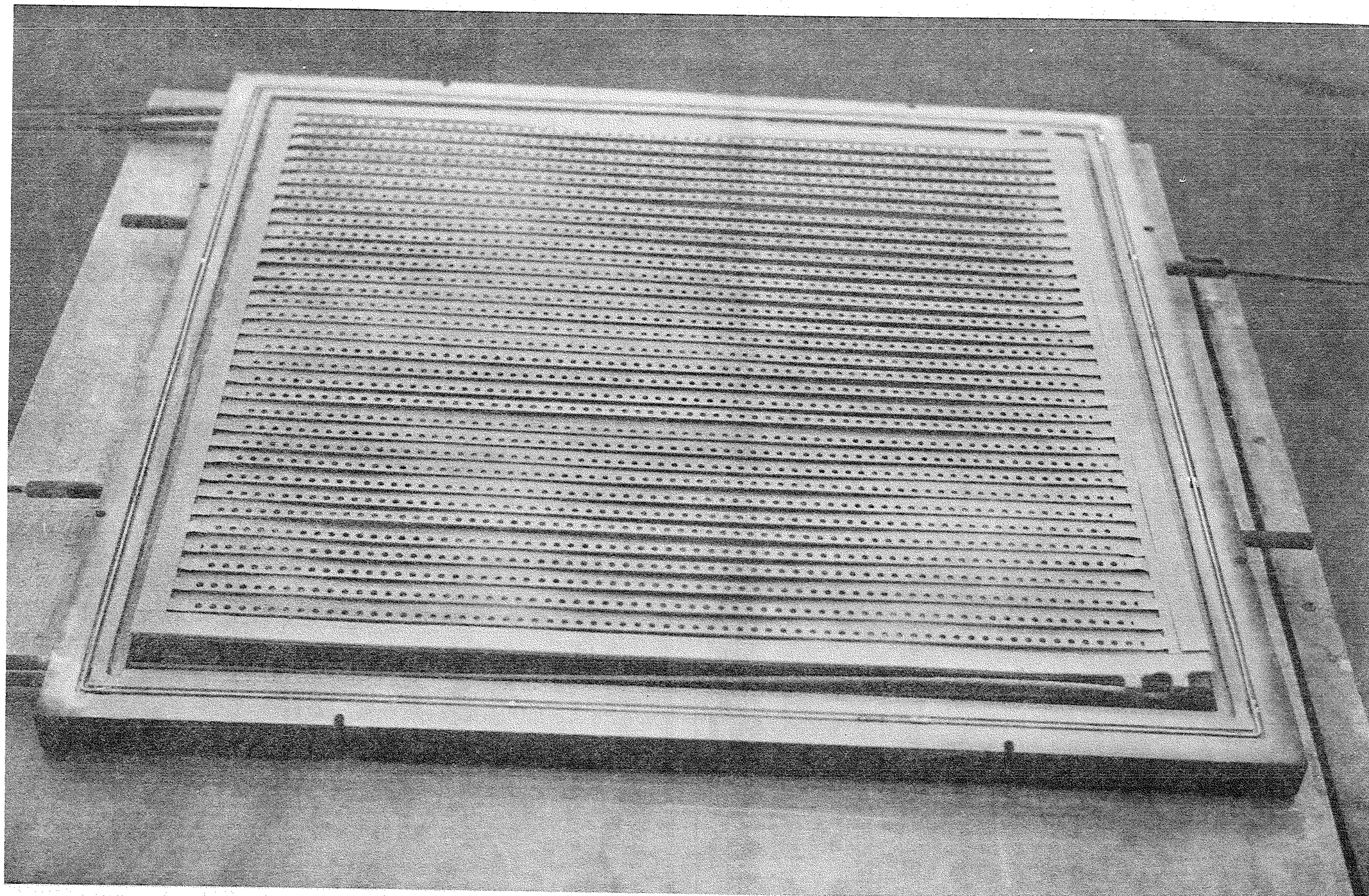
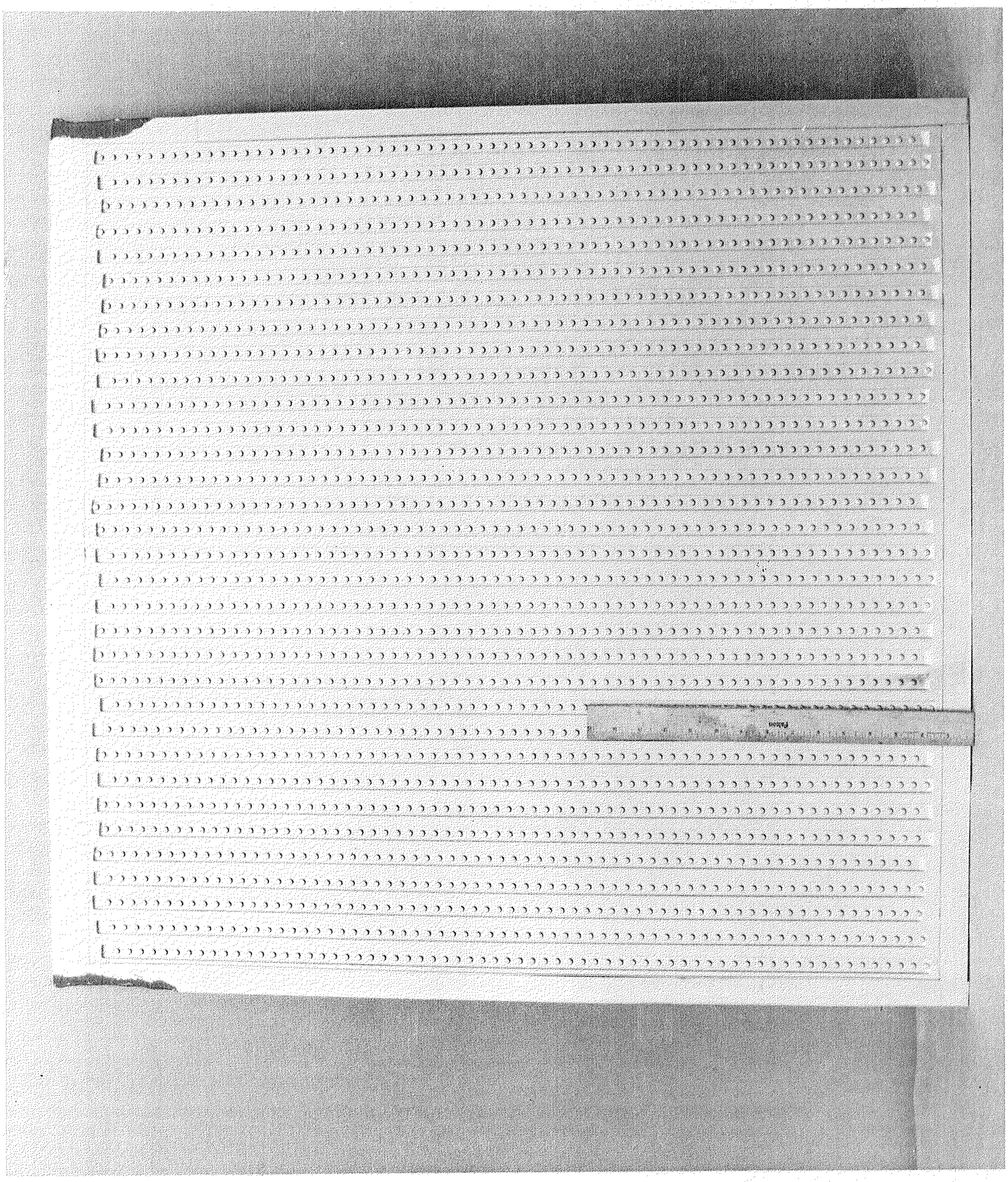


FIGURE 4.2-2 PANEL LAY-UP SHOWING PERFORATED STRIPS



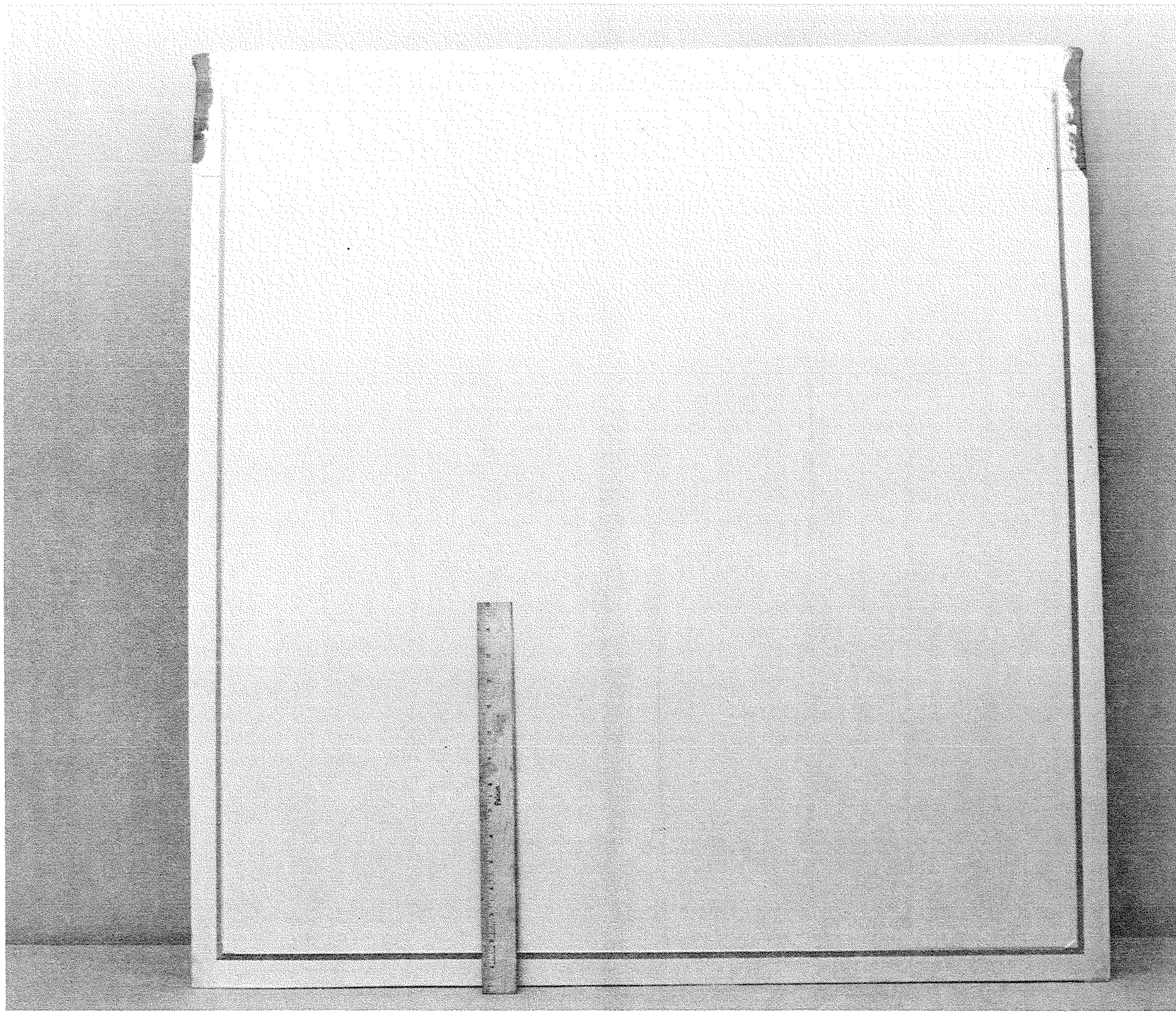
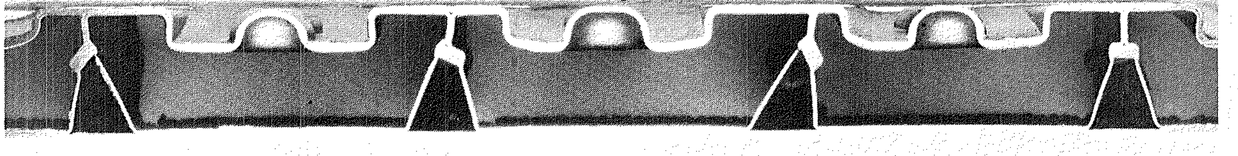


FIGURE 4.2-4 BOTTOM SIDE OF LFC DEMONSTRATION PANEL



NEG. LW-628 MAG. 1.7X

FIGURE 4.2-5 CORE CONFIGURATION, FIRST LFC PANEL
(Note: Bottom face sheet is obscured due to light background)

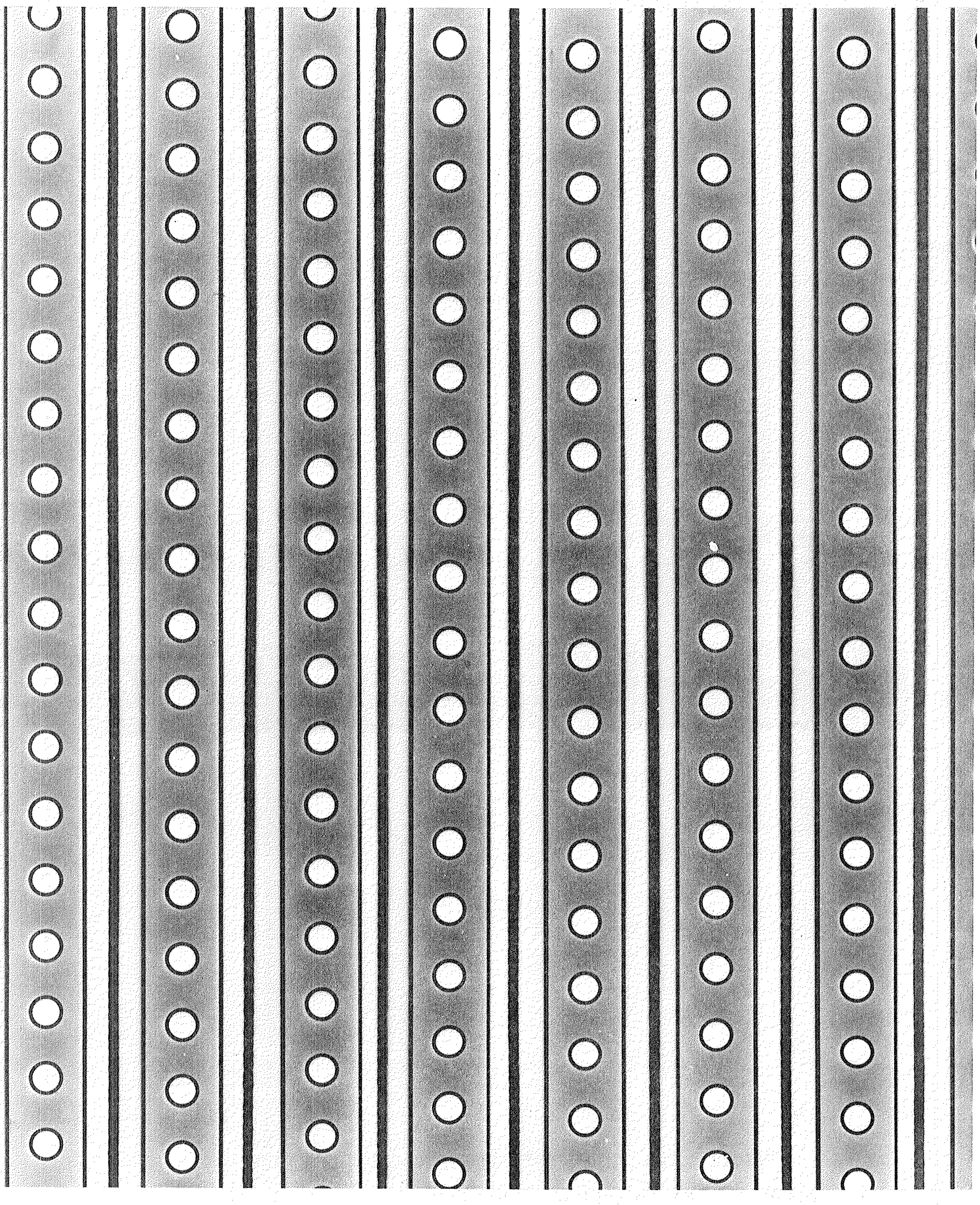
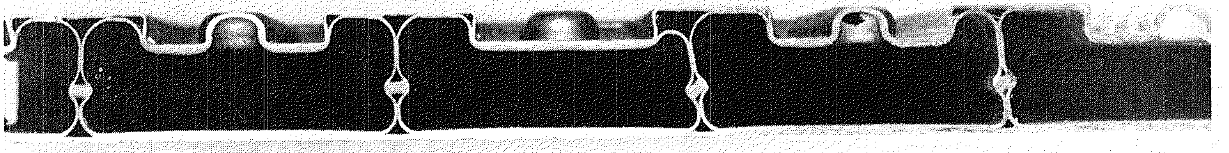


FIGURE 4.2-6 X-RAY EXPOSURE OF CORE CONFIGURATION



NEG. LW-629

MAG. 1.7X

FIGURE 4.2-7 CORE CONFIGURATION - SECOND LFC PANEL

A third panel was prepared and formed. In this panel, a face sheet exhaust channel was provided by incorporation of a transverse web connecting the longitudinal webs in an area of full height forming. In prior panels, the transverse web for exhausting face sheet gas was located at the edge of the panels where core forming height was limited by the edge tooling. The panel surfaces were smooth with no tooling pick-up. The panel was Kolene treated and chemically milled, and cut to size. Examination of the formed core configuration revealed evidence of face sheet gas entrapment. Core forming was similar to that achieved in the second panel. The cleavage at the core-to-face sheet intersections was generally uniform, except in those webs which were tilted due to misalignment with the land areas on the top side of the panel. Despite the lack of full core forming, the panel was considered adequate for LFC demonstration purposes.

The projections into the holes in the tooling strips were fully formed. These projections were removed by machining. The resulting diameter of the holes was approximately 0.200 inch i.e., the outside diameter of the tooling hole 0.240 inch minus 2 times the wall thickness of the formed projection 0.040 inch.

4.2.2 PREPARATION OF PERFORATED TITANIUM SHEET

Two sections of perforated sheet were sheared, deburred, and steam cleaned in preparation for fusion welding. The perforated sheet is available in 15-inch widths, necessitating welding of segments to provide a sheet of sufficient width to bond to the 28 x 28 inch demonstration panel. The segments were fusion welded together using the gas-tungsten arc (GTA) process on a longitudinal weld positioner. The weld was roll planished to reduce distortion, then ground and polished flush with the adjacent sheet surfaces.

The welded perforated sheet was then sealed in a stainless steel envelope which was evacuated to a pressure of 2.2×10^{-5} Torr. The envelope containing the titanium sheet was placed in a press, and the sheet was hot straightened at 1200°F for one hour with approximately 15 psi press pressure.

4.2.3 PREPARATION FOR BONDING

The faying surfaces of the perforated titanium sheet and the panel were abrasive blasted at 20 psi using new clean glass grit. The faying surface of the sheet was then primed with EC2174 primer, room temperature dried for 1/2 hour, then oven baked at 250°F for 1/2 hour. The panel surface was cleaned using methyl ethyl ketone (MEK) prior to adhesive bonding.

4.2.4 ADHESIVE BONDING

Strips of film adhesive, AF-3 (3M), 0.011 inch thick, were cut and heat tacked to the land areas of the panel. The perforated sheet was placed on the panel with the fusion weld located on one of the land areas. The assembly was then bagged and sealed for the autoclave cure. The cure cycle was 250°F for 3 hours at 25 psi pressure. After curing, the perforated titanium sheet surface was polished and cleaned with MEK. Figure 4.2-8 shows the finished panel. A close-up view of the skin and substructure is shown in Figure 4.2-9.

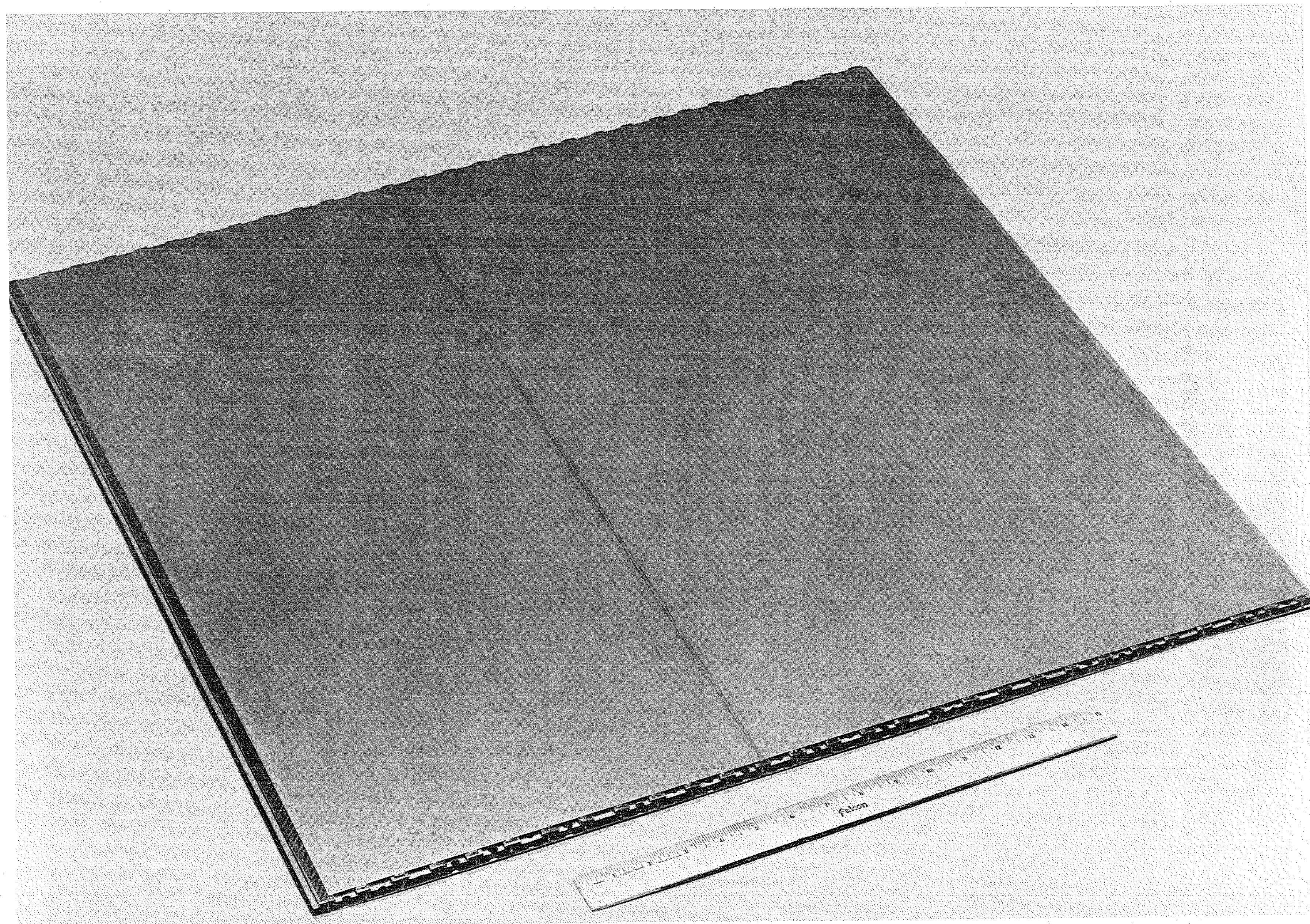


FIGURE 4.2-8 FINISHED LFC PANEL

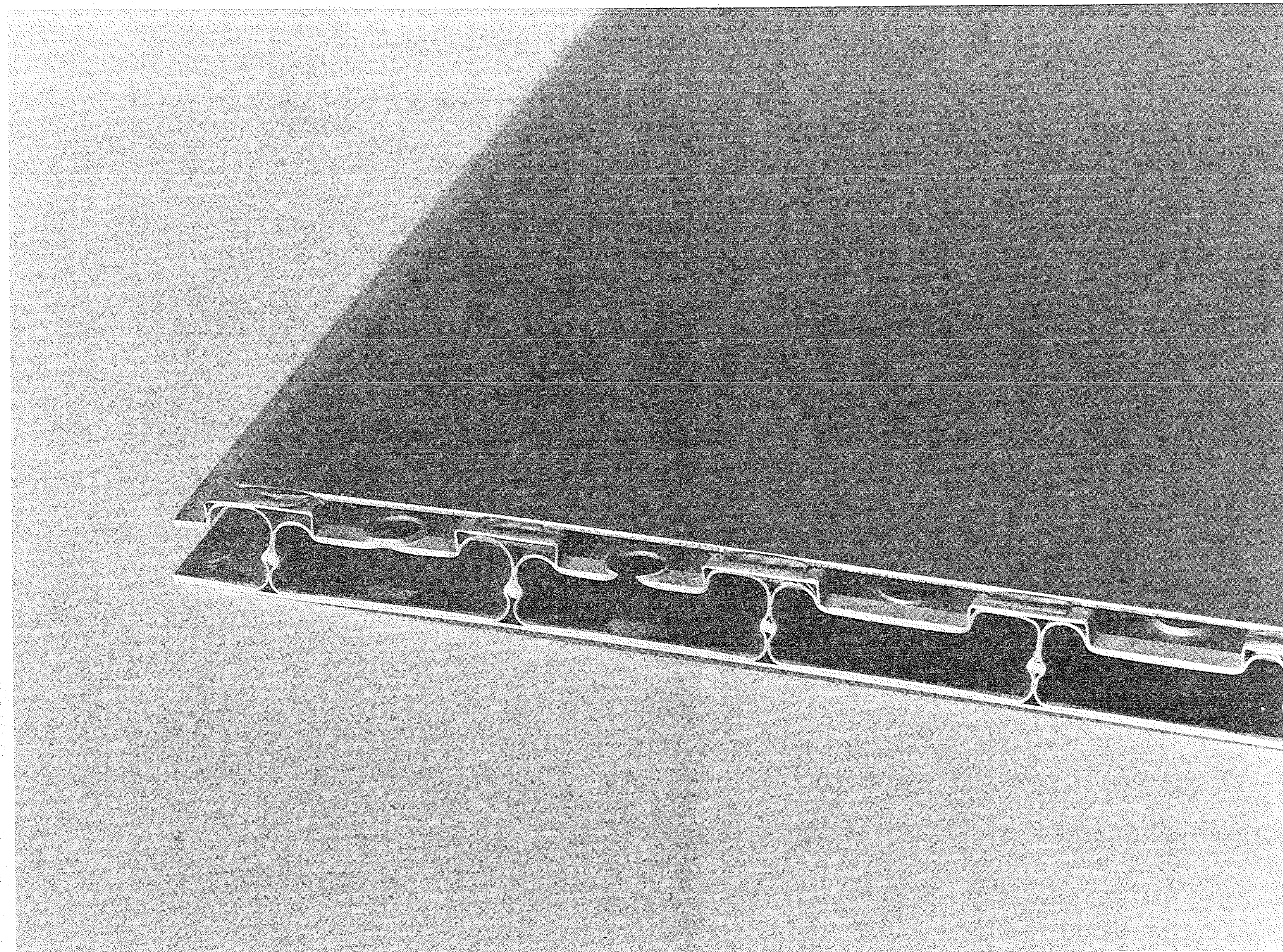


FIGURE 4.2-9 CLOSE-UP VIEW OF LFC PANEL

5.0 CONCLUSIONS AND RECOMMENDATIONS

From the development work described in this report, the following conclusions and recommendations can be made:

Special procedures are required to produce smooth panels incorporating thin face sheets. Face sheet gas pressure holds the face sheets in restraint against the limiting fixtures during forming of the core envelope. The relationship between face sheet gas pressure and final core forming is critical to avoid face sheet material gathering resulting in slight grooving (eyebrowing) at the core-to-face sheet intersections.

The type of tooling material in contact with the face sheets during forming is critical to avoid tooling pick-up. Type 430 stainless steel coated with boron nitride with a binder - acetone carrier was the only system which consistently eliminated tooling pick-up. Further work is required in this area to isolate the mechanism of tooling pick-up and develop procedures for its elimination in applications where type 430 stainless steel can not be used.

Further work is required to develop a design to assure venting of face sheet gas pressure to allow full forming of the core envelope. Face sheet gas pressure venting was a persistent problem in this program, largely attributable to the core design. In core designs having transverse as well as longitudinal webs, face sheet gas venting has not been a problem. The panels in this program, having only longitudinal webs, allowed only one transverse web at the edge of the panel for venting.

This program demonstrated the capability to produce SPF/DB titanium panels meeting the design requirements for LFC applications. It is recommended that further work be done to produce panels comprised of three sheets. In addition to the obvious weight savings gained through elimination of one face sheet, such a design would facilitate more uniform core web alignment in the land areas of the panels.

1 Report No NASA CR165818	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle LAMINAR FLOW CONTROL SPF/DB FEASIBILITY DEMONSTRATION		5 Report Date OCTOBER 1981
		6 Performing Organization Code
7 Author(s) R.C. Ecklund and N. R. Williams		8 Performing Organization Report No
		10 Work Unit No
9 Performing Organization Name and Address McDonnell Douglas Corporation Douglas Aircraft Company 3855 Lakewood Boulevard Long Beach, CA 90846		11 Contract or Grant No NAS1-16425
		13 Type of Report and Period Covered CONTRACTOR REPORT
12 Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, DC 20546		14 Sponsoring Agency Code

15 Supplementary Notes

Langley Technical Monitors: D. B. Snow; J. W. Cheely
Final Report

16 Abstract

This program was conducted to demonstrate the feasibility of applying superplastic forming/diffusion bonding (SPF/DB) technology to laminar flow control (LFC) system concepts. Procedures were developed to produce smooth, flat titanium panels, using thin -0.016 inch sheets, meeting LFC surface smoothness requirements. Two large panels 28 x 28 inches were fabricated as final demonstration articles. The first was flat on the top and bottom sides demonstrating the capability of the tooling and the forming and diffusion bonding procedures to produce flat, defect free surfaces. The second panel was configurated for LFC porous panel treatment by forming channels with dimpled projections on the top-side. The projections were machined away leaving holes extending into the panel. A perforated titanium sheet was adhesively bonded over this surface to complete the LFC demonstration panel. The final surface was considered flat enough to meet LFC requirements for a jet transport aircraft in cruising flight.

17 Key Words (Suggested by Author(s)) Superplastic Forming/Diffusion Bonding SPF/DB Laminar Flow Control	18 Distribution Statement UNCLASSIFIED - UNLIMITED

19 Security Classif (of this report) UNCLASSIFIED	20 Security Classif (of this page) UNCLASSIFIED	21 No of Pages	22 Price

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161

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